An investigation into independent practice as an addition to physiotherapy intervention for patients with recently acquired stroke.

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AN INVESTIGATION INTO INDEPENDENT PRACTICE AS AN ADDITION TO PHYSIOTHERAPY INTERVENTION FOR PATIENTS WITH RECENTLY ACQUIRED STROKE

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Abstract

This study of physiotherapy intervention for patients with recently acquired stroke had two defined aims. The first aim was to explore the recovery of symmetry of weight distribution during the postures of sitting and standing and during the movements of rising to stand, sitting down and reaching. This aim involved the comparison of data from stroke patients with data from healthy subjects. The second aim was to determine the effect of a regime of independent practice, based on the evidence for the optimal learning of motor skills. This aim was met using a randomised controlled trial.

Twenty-eight patients with stroke were recruited into the randomised controlled trial. Using a blocked randomisation procedure, subjects were assigned to a practice group (n=9) or to a control group (n=19). Using a clinical measurement system, comprising a standard chair and a platform within which were a series of force measuring sections, weekly objective measurements of the symmetry of weight distribution during the specified postures and movements were recorded. Measurements were collected weekly for a maximum of 7 weeks. Both groups received normal physiotherapy intervention, based on the Bobath Concept. In addition to this, the practice group subjects carried out a practice regime aimed at improving sitting balance. The practice regime was carried out daily for 4 weeks. Subjects who were discharged from the hospital prior to the completion of 7 weeks of data collection did not attend for any further measurement sessions. The lack of recorded data from subjects discharged from the hospital placed limitations on the analysis of the study results and on the conclusions that could be drawn from the study.

In order to explore the recovery of symmetry of weight distribution in the patients with stroke, patient data were compared with "normative" values collected from 20 young and 20 elderly healthy subjects. The normative values revealed that healthy subjects tended to have highly symmetrical weight distribution, with less than 14% difference in weight distribution between the sides, during sitting, standing, rising to stand and sitting down. During lateral reaching healthy subjects generally distributed between 83% and 97% of body weight to one side.

At the time of the baseline measurement 13 (11 control group; 2 practice group) of the 28 patients had "normal" weight distribution in sitting; 2 (1 control; 1 practice) in standing; 1 (1 control; 0 practice) in the seat-off phase of rising to stand; 0 in the seat-off phase of sitting down. 10 (8 control; 2 practice) of the patients achieved a "normal" magnitude of weight transference when reaching to the unaffected side, and 13 (10 control; 3 practice) during reaching to the affected side. Following reaching to the unaffected side 12 (9 control; 3 practice) of the patients returned to having "normal" weight distribution in sitting, and following reaching to the affected side 12 (7 control; 5 practice) had "normal" weight distribution in sitting.

At the time of the final measurement, 11 (58%) of the 19 control group subjects had "normal" weight distribution in sitting; 7 (36%) in standing; 6 (31%) in rising to stand; 2 (11%) in sitting down; and 12 (64%) achieved "normal" weight transference during reaching to the unaffected side and 13 (68%) during reaching to the affected side. 13 (69%) of the control group subjects achieved "normal" weight distribution during sitting following reaching to the unaffected side, and 10 (53%) during sitting following reaching to the affected side. For the practice group these values were 3 (33%) for sitting; 4 (44%) for standing; 1 (11%) for rising to stand; 1 (11%) for sitting down; 4 (44%) for reaching to the unaffected side and 6 (67%) for reaching to the affected side; and 4 (44%) for sitting after reaching to the unaffected side and 5 (56%) for sitting after reaching to the affected side.

Statistical analysis was carried out, using the Chi-squared test, to compare the proportion of control and practice group subjects classified as "unable" to perform a task, or as achieving "normal" or "abnormal" outcomes during each test week. There was no significant difference ($p>0.05$) between the groups for the tasks of sitting, standing, rising to stand or sitting down, or for the peak weight transference achieved during reaching, on any of the test weeks. There was a significant difference between the groups for the symmetry of weight distribution achieved during sitting following reaching to the unaffected side at week 3 ($p=0.016$) and during sitting following reaching to the affected side at week 4 ($p=0.027$). Descriptive statistics were used to explore the changes in the outcome measures over the test weeks. This revealed that, although the number of subjects able to perform standing, rising to stand and sitting down increased over the test weeks, there was no observable change in the proportion of subjects able to perform any of the tasks with "normal" symmetry of weight distribution or weight transference over the study period.

The lack of difference in the outcome of the practice and control group and the absence of recovery observed in the measured outcomes over the study period are discussed. Based on the study results, methods for improving the regime of independent practice are presented, and potential implications of the lack of change in the ability of the stroke patients to achieve the functional tasks with "normal" symmetry of weight distribution are proposed.

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Contents

1. Stroke and physiotherapy

1.1 Background to study

Substantial resources are utilised by physiotherapists in the care and rehabilitation of patients following stroke. There are currently several different approaches to physiotherapy for patients with stroke. The Bobath approach (Bobath, 1978, 1990; Davies, 1985, 1990) and the Motor Learning approach (Carr and Shepherd, 1989b, 1990, 1992) are widely recognised as being the most common strategies adopted in the treatment of patients with stroke. A key practical difference between the two approaches appears to be that treatment based on the Motor Learning approach can involve a patient participating in independent practice, while treatment based on the Bobath approach will not involve any independent practice. Despite the apparent contradiction in the theory and practice of these two approaches, both concur that a key role of the physiotherapist in the treatment of patients with stroke is the achievement of optimal functional ability (Carr and Shepherd, 1989a,b; Bobath, 1990; Ashburn, 1995). The restoration of balance is proposed to be a fundamental goal of physiotherapy for acute stroke patients by proponents of both the Bobath and the Motor Learning approach. There is an absence of scientific evidence pertaining to the relative efficacy of the different treatment strategies in the achievement of the goals of physiotherapy. It is imperative that well-controlled studies of physiotherapy interventions are carried out in order to determine optimal methods of patient care.

Randomised controlled trials are widely recognised as the optimal experimental methodology for determining cause and effect (Begg et al, 1996). The execution of a randomised controlled trial in the investigation of the effect of a physiotherapy intervention is complex. Randomised controlled trials should incorporate strictly standardised methodologies to ensure methodological rigour (Bland, 1995).

The object of this study was to investigate the effect of independent practice, which is advocated by the Motor Learning approach but not by the Bobath approach, on the restoration of balance, which is identified as a fundamental goal of treatment by both the Motor Learning and Bobath approach. Strict standardisation of independent practice aimed at improving clearly defined aspects of balance was required in order to achieve methodological rigour within the context of a randomised controlled trial.

This chapter comprises a review of the literature pertaining to stroke and physiotherapy and identifies that the restoration of balance is a common goal of physiotherapy treatment for patients with acute stroke

1.2 Epidemiology of stroke

Stroke is a major cause of death and disability and has significant cost implications for health care services. In Western populations stroke is the third leading cause of death and the leading cause of disability (Warlow et al, 1996; Hademenos and Massoud, 1997). The World Health Organisation stated that stroke is the second most common world-wide cause of death (WHO, 1997). In Britain it is estimated that there are 2 first strokes per 1000 people per year (Bamford et al, 1988). The rate of stroke increases with age, and it has been predicted that this will place health care services under increasing strain (Kings Fund Forum, 1988). Studies have demonstrated that up to 75% of patients with stroke are admitted to hospital (Aho et al, 1980; Bamford et al, 1986), and that approximately 12% of general medical beds are occupied by patients with stroke (Kings Fund Forum, 1988). In Scotland 7% of all hospital-bed days and 6% of all hospital costs are due to stroke (Isard and Forbes, 1992). Almost 5% of the NHS budget in Scotland is consumed by costs related to patients with stroke (Isard and Forbes, 1992). It is estimated that the majority of this expenditure is related to the rehabilitation and long-term care of patients following stroke (Bergman et al, 1995). Despite these substantial financial resources there is little data available pertaining to the cost-effectiveness of stroke rehabilitation (Wade and Langton-Hewer, 1987; Effective Health Care, 1992).

It has been suggested that stroke is the most frequent cause of disability in the UK (Harris and Head, 1971; Warlow et al, 1996). Patients with stroke therefore have a major impact on the resources used both while in hospital and following discharge. Partridge et al (1993) stated that the majority of patients admitted to a UK hospital with a stroke, who survived with a residual disability, would receive both physiotherapy and occupational therapy as part of their care. In a survey of service provision following discharge from hospital, patients with stroke in South East

London reported receiving a number of health / support related services - 39% had received physiotherapy; 13% speech therapy; 6% occupational therapy; 30% chiropody; 29% district nursing; 24% had attended a day centre; 12% day hospital; 22% had received local authority home help; 6% private home help; 16% meals on wheels; 5% respite care; 2% had seen a community psychiatric nurse (Wilkinson et al, 1997). Despite the potential effects of recall bias due to the retrospective nature of the study (Wilkinson et al, 1997), these results do suggest that substantial resources are utilised by patients with stroke.

1.3 Aetiology of stroke

Stroke is a broad diagnostic term that refers to a dysfunction in the blood supply to an area of the brain (Effective Health Care, 1992). The World Health Organisation defines stroke as the "sudden onset of a focal neurological deficit due to a presumed local disturbance in the blood supply to the brain" (Aho et al, 1980). The normal functioning of the brain is reliant on the arterial blood supply, which delivers vital oxygen and nutrients, and the venous system, which removes cellular metabolic waste products (Hademenos and Massoud, 1997). Any disturbance to the arterial supply results in oxygen deprivation in the areas of the brain supplied by the occluded vessel, which can consequently result in brain injury. Hademenos and Massoud (1997) state that

> "The severe restriction or complete cessation of blood flow to the brain as the result of any cerebrovascular disease or neurological insult (brain injury) is commonly referred to as stroke".

The magnitude of the brain injury and the consequent deficits are reliant on the extent and cause of the disturbance in blood flow, as well as the area of the brain supplied by the affected blood supply. Neurological deficits as a result of cerebral ischaemia which appear rapidly but which resolve within 24 hours are called Transient Ischaemic Attacks (TIAs). More severe disruption to blood supply can lead to loss of brain function which can cause varying degrees of disability (permanent stroke) or death.

Stroke, or cerebrovascular accident (CVA), primarily occurs as a result of an occlusion in blood supply (thrombus or embolus) or as a result of a rupture of blood vessels (haemorrhage). However, Hademenos and Massoud (1997) identify that there are 6 distinct biophysical mechanisms that can result in stroke. These are:-

1. **Atherosclerosis.** Atherosclerotic deposits are residues of calcified lipid or fatty remains from the blood, which accumulate on the inner walls of blood vessels. This promotes the thickening, fibrosis and calcification of the vessel wall, which narrows the lumen of the blood vessel. The narrow lumen may increase the shear stresses of the blood flow, which may result in further damage to the vessel wall. The turbulence of the blood flow may increase, either causing disturbance to the existing atherosclerotic plaques and creating loose sections of plaque, which may obstruct blood flow in smaller vessels, or resulting in areas of stagnant blood flow and the formation of additional atherosclerotic deposits.
2. **Embolus.** An embolus is a travelling "clot", which can be gaseous or particulate (e.g. atheromata) matter from any part of the circulation system.
3. **Thrombus.** Thrombosis is the physiological mechanism for blood clotting. A thrombus is a blood clot, which has formed either in response to an atherosclerotic lesion or to damage to a vessel wall.
4. **Reduced systemic pressure.** Stroke can be caused secondary to cardiovascular disease, such as atrial fibrillation, MI, and abnormal heart beat, which can reduce the pressure of the arterial blood supply.
5. **Haemorrhage.** A haemorrhage is the rupture of a blood vessel and the subsequent accumulation of blood in the brain. Haemorrhage can result in brain damage from the reduction in blood supply to the areas supplied by the damaged vessel, by the pressure exerted on tissues at the site of the haemorrhage, and by the occlusion of surrounding blood vessels by the leaked and thrombosing blood. Blood vessel rupture can be caused by an aneurysm or an arteriovenous malformation (AVM).
6. **Vasospasm.** When bleeding occurs in the subarachnoid space, the arteries in the subarachnoid space can have a muscular contraction known as vasospasm. This vasospasm can cause total occlusion of the blood vessel, which can last for up to several days. (Hademenos and Massoud, 1997)

It has been estimated that approximately 70% of strokes occur due to occlusion of blood vessels by thrombus or embolus; approximately 20% occur as a result of haemorrhage; and the remaining 10% occur for other reasons (Ryerson, 1996).

Hademenos and Massoud (1997) concur with this, stating that 80% of strokes result from ischaemia following obstruction to a blood vessel, and 20% are due to haemorrhage.

Strokes have traditionally been classified according to the pathological type (Ryerson, 1996). The types generally described are thrombus, embolus and haemorrhage (Ryerson, 1996; Warlow et al, 1996). However, Bamford et al (1991) recognised that the identification of the pathology of the stroke could be difficult, and defined an alternative classification system, based on a study of 675 patients with a first-ever stroke (diagnosed from computed tomographic scans). This study identified 4 main subtypes of infarcts, according to the presenting signs and symptoms of the patient at the time of maximum deficit (Bamford et al, 1991):-

- **Lacunar infarcts (LACI).** These infarcts resulted in pure motor stroke, pure sensory stroke, sensori-motor stroke or ataxic hemiparesis. These symptoms occurred as a result of a small lacunar infarct in the basal ganglia or the pons.
- **Total anterior circulation infarcts (TACI).** TACIs resulted in higher cerebral dysfunction; homonymous visual field defect; and an ipsilateral motor and/or sensory deficit in at least two areas of the face, arm or leg. TACIs occurred due to ischaemia in both the deep and superficial areas of the middle cerebral artery.
- **Partial anterior cerebral infarcts (PACI).** Patients with PACIs present with only 2 of the 3 components of a TACI, with higher cerebral dysfunction alone, or with a sensori-motor deficit that is more restricted than the LACI. A PACI occurs as a result of occlusion to the upper or lower division of the middle cerebral artery, or an occlusion in the anterior cerebral artery.
- **Posterior circulation infarcts (POCI).** POCIs can cause any of the following symptoms: ipsilateral cranial nerve palsy with contralateral motor and/or sensory deficit; bilateral motor and/or sensory deficit; disorder of conjugate eye movement; cerebellar dysfunction without ipsilateral long-tract deficit (i.e. ataxic hemiparesis); or isolated homonymous visual field defect. These symptoms are associated with infarcts in the brain stem, cerebellum or occipital lobes.

Lindley et al (1993) investigated the interobserver reliability of the classification system proposed by Bamford et al (1991). 90 patients admitted to a general hospital, over a 5 month period, with suspected stroke were independently assessed by 2 medically trained observers, within 2 and 10 days of the onset of symptoms. Each of the patients was classified as TACI, PACI, LACI, POCI or 'uncertain'. The 2 observers agreed on 56% of the classifications; this increased to 74% in the classifications with which both observers were certain. The reasons for disagreement on the classification were found to be due to differences elicited in neurological tests, the assessment of the presence or absence of confusion, the presence of deep coma, and an inadequate clinical history. In 5 of the patients assessed the observers agreed on the neurological signs but disagreed on the classification. The authors concluded that the interobserver reliability might be further improved if the documented clinical history included a record of the maximum deficit. The authors proposed that the classification system might be useful in routine clinical practice.

Lindgren et al (1994) further evaluated the classification system proposed by Bamford et al (1991), in a study which related the classification of patients to CT and MRI brain scan results. 228 patients with first-ever strokes admitted to hospitals within a specified catchment area over a period of 1 year, were assessed by two neurologists on separate occasions within one week of onset of symptoms. Based on these documented assessments the patients were classified according to the system proposed by Bamford et al, by two independent observers. The interobserver agreement was 92%. The authors acknowledged that this was higher than found in earlier studies, such as Lindley et al (1993). It was proposed that this difference was due to the assessment protocol used in this study, and the availability of the assessments of the two neurologists to the observers classifying the patients. Where the two observers did disagree, a joint re-evaluation was carried out and a classification assigned. All patients underwent a CT or MRI examination as soon as possible after the onset of symptoms. The results of the scans were examined and the lesions were described according to type, size, side, location and arterial territory. The neuroradiological findings were then compared with the classification of stroke type. The patients in the different groups were found to have significantly different frequencies of specified neuroradiological signs. For example, there was a significant difference in the presence of haemorrhage ($p<0.01$); presence of cortical involvement

($p<0.01$); and presence of posterior circulation territory involvement ($p<0.0001$). Thus the authors concluded that the classification system produced groups of patients who had significant differences in neuroradiological findings. Lindgren et al (1994) proposed that this classification system was an easily administered, reliable, distinctive, and clinically useful method of grouping sub-types of stroke.

In addition to the 4 categorisations of cerebral infarcts, strokes can also occur due to cerebral haemorrhage. Two classifications of haemorrhagic stroke are described in the literature: a **primary intracerebral haemorrhage (PICH)**, which is a bleed occurring most frequently within the internal capsule and corpus callosum; and a **subarachnoid haemorrhage (SAH)**, which is a bleed into the subarachnoid space (Effective Health Care, 1992).

1.4 Symptoms and disability following stroke

The clinical symptoms which occur following stroke are dependent on the size and location of the area of disrupted blood supply, and the anatomical structures which are involved (Ryerson, 1996). The nature and extent of dysfunction following stroke can therefore be extremely varied. Wade et al (1985b) stated that there were 3 main classes of neurological symptoms following stroke - cognitive, communicative and physical dysfunction. Effective Health Care (1992) estimated that approximately 50% of survivors of strokes have significant disability due to paresis, communication or cognition.

Cognitive and communicative symptoms can include an extensive range of deficits, including impairments in memory, language, and perception. The cognitive and communicative symptoms that occur following stroke can be related to the side of the lesion, as each hemisphere has specific functions. For example, damage to the left hemisphere is generally associated with disorders in language, specific perceptual disorders and apraxia. Right hemispheric damage is associated with major perceptual dysfunction, such as visual spatial neglect, tactile perceptual disorders and constructional apraxic deficits (Wade et al, 1984). Despite the distinct differences in the symptoms arising from damage to the left and right hemispheres, there is little evidence provided in the literature that suggests that recovery is related to the side of hemispheric damage. Wade et al (1985b) proposed that the specific problems associated with lesions to either hemisphere tend to balance each other out. However, Rode et al (1997) reported differences in the balance ability of patients with left and right hemispheric lesions. Following an investigation of postural imbalance in 15 patients with left hemiplegia and 15 patients with right hemiplegia, Rode et al (1997) concluded that patients with damage to the right hemisphere demonstrated greater postural imbalance. The authors proposed that this difference was due to the spatial disturbances arising from damage to the right hemisphere. Thus there is limited evidence that motor ability in subjects with left and right hemiplegia may differ.

Ryerson (1996) suggested that the most obvious clinical symptoms following stroke are hemiplegia and motor dysfunction. Ashburn (1997) described the most common deficit as motor impairment, yet stressed that not all strokes resulted in physical symptoms. This was supported by studies of recovery and function in stroke patients (Dombovy, 1991) which indicated that one week following stroke 73-88% of patients have some degree of hemiparesis (Kotila et al, 1984; Wade and Langton-Hewer, 1987; Bonita and Beaglehole, 1988). Hemiplegia refers to the loss of motor function on one side of the body; hemiparesis to a weakness on one side of the body. In addition to the motor loss there can be partial or complete loss of sensory perception. The severity of the hemiparesis and motor symptoms are related to the degree of damage to the motor and sensory fibres within the CNS. In addition to the loss of movement related to sensori-motor dysfunction, the tone of the muscles may be altered. Altered muscle tone occurs in response to the dysfunction of the normal control mechanisms for spinal reflex activity. Problems with balance and the maintenance of posture frequently occur in many patients with stroke (Ashburn, 1997).

1.4.1 Assessment of disability following stroke

The symptoms experienced by patients following stroke result in impaired ability to carry out functional tasks, and activities of daily living (ADL). There is no one accepted instrument for assessing disability following stroke (Wade and Langton-Hewer, 1987; Turner-Stokes and Turner-Stokes, 1997). A recent survey of outcome measures used in rehabilitation settings has found that the most commonly used instruments are subjectively scored or rated global measures of disability (Turner-

Stokes and Turner-Stokes, 1997). The most widely used assessment scale is the Barthel Index (Wade and Langton-Hewer, 1987; Turner-Stokes and Turner-Stokes, 1997) (see Appendix A). Although the Barthel Index is recognised to lack sensitivity and to have a ceiling effect (Wade, 1992) it has been demonstrated to be a valid score (Wade and Langton-Hewer, 1987), and has been proposed as a "satisfactory measure of function after stroke" (Wade and Langton-Hewer, 1987). However, it has been suggested that the lack of sensitivity of the Barthel Index may contribute to the non-significant results found in some studies of functional outcome following stroke (Miyai et al, 1997).

Wilkinson et al (1997) investigated the long-term outcome (approximately 5 years after stroke) of patients on the stroke register in South East London. Disability measures recorded using the Barthel scale indicated that 13% of the 77% of survivors followed up were very severely or severely disabled (Barthel 0-9); 16% were moderately disabled (Barthel 10-14); 37% were mildly disabled (Barthel 15-19); and 34% were functionally independent (Barthel 20) (Wilkinson et al, 1997). Dombovy (1991) estimated from the available literature that at one week following a stroke 68-88% of patients are dependent in some aspect of ADL; after 6 months this has reduced to 40-60% of patients being dependent in some aspect of ADL and after 1 year there is a further small reduction to 33-59%. The functional outcome following stroke has been shown, from a study of 680 patients with stroke, to be associated with the severity of the stroke (Bonita and Beaglehole, 1988). Although the results from different studies cannot be directly compared due to the differences in the populations studied, in the methods of assessment, and in the severity of the strokes, these studies do illustrate that stroke is a major cause of long-term functional disability.

An additional method of assessing outcome following stroke is to determine the length of hospital stay. Wade and Langton-Hewer (1987) proposed that the majority of the financial cost of stroke was related to the length of hospital stay. A number of studies have suggested that the majority of the motor recovery following stroke occurs in the first few weeks following stroke (Wade et al, 1983; Smith et al, 1985; Wade et al, 1985b; Olsen, 1990). It can be hypothesised that the first few weeks following stroke are the most critical during the rehabilitation of motor ability following stroke.

1.4.2 Sensory-motor deficits in the patient with recently acquired stroke

The clinical symptoms observed in a patient with recently acquired stroke can include wide ranging deficits of movement and function. However, a common sensori-motor deficit that occurs is the loss of ability to control aspects of balance (Knott and Voss, 1968; Brunnström, 1970; Bobath, 1978, 1990; Davis, 1985, 1990; Carr and Shepherd, 1989 1992; Ashburn, 1997). This can present as an inability to maintain a posture independently, an abnormal alignment of body parts with asymmetry of posture and movement, an inability to adjust to alterations in the centre of gravity, and an inability to control the body parts during movement (Bobath, 1978, 1990; Davis, 1985, 1990; Carr and Shepherd, 1989, 1992; Ashburn, 1997). The patient with recently acquired stroke can present with balance deficits in any posture or during any movement; however, several authors have identified specific problems related to balance in sitting (Brunnström, 1970; Bobath, 1978; Lane, 1978; Davies, 1985; Borello-France et al, 1988) and standing (Dickstein et al, 1984; Bohannon and Larkin, 1985; Caldwell et al, 1986; Dettman, 1987; Shumway-Cook et al, 1988; Sackley, 1991), during the dynamic activities of rising to stand and sitting down (Engardt and Olsson, 1992; Durward, 1994), and during weight-shifting activities such as reaching (Chari and Kirby, 1986; Crosbie et al, 1995; Dean and Shepherd, 1997).

Wade and Langton-Hewer (1987) assessed 545 patients within 7 days of a stroke. The results demonstrated that 47% of patients were unable to maintain sitting balance within 1 week following stroke. Wade et al (1983) carried out a study, which explored the possibility of attempting to predict the functional outcome of early stroke patients. A sample of 162 acute stroke patients was assessed 1, 3, 6, 12, 18, 24, and 36 months following stroke. Five variables from the initial assessment were found to correlate (R=0.62) with the functional outcome (Barthel score) at 6 months: these variables were the presence of urinary incontinence, the degree of motor deficit in the affected arm, the ability to maintain sitting balance, the presence of hemianopia, and age. These variables explained 38% of the variance in the functional outcome. This study demonstrated that sitting balance is one of the important factors to be considered in the acute stroke patient.

Bohannon (1989) assessed balance and parameters of gait in 33 stroke patients at approximately 30 (30.4±14.6) days and 60 (64.2±18.2) days after stroke. Standing balance was found to be an indicator of gait performance. Retrospective studies of outcome of stroke patients have also found that sitting balance at the initial assessment can be indicative of future gait ability (Keenan et al, 1984; Nitz and Gage, 1995). Dettman et al (1987) and Sackley (1990) found that aspects of standing balance correlated with functional ability following stroke. These studies further demonstrate the importance of balance during the maintenance of sitting and standing, and during movement between these postures, in the stroke patient.

Partridge et al (1993) carried out a prospective study of the achievement of motor milestones in patients with stroke. 148 therapists from 30 hospitals, in 22 health districts in England, collected data on stroke patients, using a standard form which assessed the achievement of 13 milestones. Data was collected on each patient for 6 weeks. Data on 348 patients was successfully returned. This data demonstrated that, on the initial assessment, 67.2% of patients could sit for 1 minute; 29.3% could rise to stand; and 11.8% could walk independently. (Data was provided for the other 10 functional tasks). Separating the patients into groups of mild, moderate and severe disability, using the Barthel Index scores, illustrated that there was a relationship between the degree of disability and the milestones achieved. Whilst the failure of the authors to provide a standard explanation of the milestones, and the use of the large number of therapists from different hospitals, could limit the reliability and validity of these results; these data further serve to emphasise the balance-related difficulties experienced by patients with acute stroke.

Smith and Baer (in press) carried out a prospective study of 229 patients consecutively admitted to an acute stroke unit. Physiotherapists documented the dates on which patients achieved specified "milestones" of recovery. The milestones were 1) 1 minute of independent sitting; 2) 10 seconds of independent stance; 3) 10 consecutive steps; 4) 10 metres walking (timed test). A standardised protocol was written for each of the four milestones. The patients were categorised according to their stroke classification, as proposed by Bamford et al (1991) - PACI, TACI, LACI, POCI or PICH (see section 1.3). Smith and Baer (in press) found that 94.3% of the

229 patients achieved the goal of 1 minute of independent sitting, taking a mean time of 3.0±6.8 days from the day of stroke to achievement. Over 92% of each subgroup achieved this goal, with the exception of the TACI group, only 77.3% of which achieved independent sitting. The TACI group took an average of 13.4±10.4 days to achieve the goal. 86% of the patients achieved 10 seconds independent stance; taking a mean time of 11.1±21.1 days. Over 89% of each subgroup achieved this goal; with the exception of the TACI group, only 52.3% of which gained independent stance, taking an average of 52.9±29.2 days until successful. The pattern of achievement of 10 steps and 10 metre walk was similar, with over 91% of the PACI, LACI and POCI groups achieving these goals; over 71% of the PICH group achieving both goals; and only around 29-36% of the TACI group successfully achieving these milestone. This study, which used simple measures, demonstrated the existence of problems relating to sitting and standing balance and the length of time that it can take patients to achieve these milestones. In addition, Smith and Baer (in press) have highlighted the differences in outcome for patients with different classification of stroke: the authors suggest that the classification system proposed by Bamford et al (1988) can assist in the prediction of recovery outcome in the acute stroke patient.

1.5 Rehabilitation following stroke

The aims of rehabilitation after stroke have been identified by WHO (1989) as

- aiding physical recovery;
- encouraging a return to independence and activities of daily living;
- promoting physical, psychological and social adaptation to stroke-related disability and handicap;
- preventing secondary complications.

The general aim of rehabilitation following stroke is therefore to maximise a patient's functional ability, quality of life and ability to maintain an independent lifestyle. The process of rehabilitation involves a multidisciplinary team, including the patient and the patient's family. Although all members of the multidisciplinary team have the same general aim of rehabilitation, each member of the team will have a specific focus on a different aspect of rehabilitation. The key role of the physiotherapist in the process of rehabilitation is to address issues related directly to the sensori-motor deficits and resulting physical dysfunction of the patient (Ashburn, 1995).

1.5.1 Physiotherapy for the early stroke patient

A fundamental goal of physiotherapy for the acute stroke patient is the restoration of balance (Bobath, 1978, 1990; Davis, 1985, 1990; Partridge et al, 1987; Carr and Shepherd, 1989, 1992; Gerber, 1995). The majority of the proponents of physiotherapy approaches for the early stroke patient identify that an initial aim of treatment will be to improve a patient's ability to maintain balance in sitting (Brunnström, 1970; Bobath, 1978, 1990; Lane, 1978; Davis, 1985, 1990; Carr and Shepherd, 1989 1992; Gerber, 1995). Later treatment aims include the restoration of balance in standing, and during dynamic activities such as reaching, rising to stand, and sitting down (Davis, 1985; Carr and Shepherd, 1989, 1992; Bobath, 1990).

There are a number of different approaches to physiotherapy for patients with stroke (Brunnström, 1970; Bobath, 1978, 1990; Davis, 1985, 1990; Carr and Shepherd, 1989, 1992). However, the general aim of the different approaches is for the patient to achieve optimal functional ability (Carr and Shepherd, 1989; Bobath, 1990; Ashburn, 1995). Despite differences in the concepts of treatment for acute stroke patients, a key aim identified by the various physiotherapeutic approaches is the improvement of balance.

1.6 Study in context and introduction to review of the literature

A key aim of the physiotherapist is to maximise a patient's functional ability and independence. A common sensori-motor problem in the early stroke patient is the inability to maintain balance or to control balance during movement. Despite contrasts in the practice and theory of different physiotherapy treatment approaches for patients with stroke, a common aim of treatment is the improvement of balance during the maintenance of postures such as sitting and standing, during movement within a posture (such as reaching), and during movement between postures (such as rising to stand and sitting down). The goal of this study was to explore the recovery of balance during the specified postures and movements and to investigate the effect of a regime of independent practice aimed at improving balance on the functional outcome of patients with stroke.

The following chapters review the nature of problems relating to balance and identify appropriate methods for the assessment of problems relating to the maintenance of balance during sitting, standing, rising to stand, sitting down and reaching. Subsequent chapters highlight the literature pertaining to the optimal acquisition of motor skills in order to allow the development of a regime of independent practice based on the available evidence. The evidence in support of different physiotherapy approaches is identified and discussed in relation to recovery following stroke, and studies investigating the relative efficacy of different physiotherapy approaches for the treatment of patients with stroke are reviewed. This review of the literature forms the evidence on which a specific set of study aims, objectives and hypotheses were formulated and tested.

2. What is balance?

2.1 *Mechanical Definitions*

2.1.1 Balance and Equilibrium

The use of the word balance derives from Roman times and to the description of an instrument used for comparing the weights of two objects using two scale pans (*bi* = two, *lanx* = scale pans). Today this instrument is often referred to as a balance beam. The word equilibrium also derives from the Latin, coming from *aequilibrare*. The definition of *aequilibrare* is "to balance". Thus the terms balance and equilibrium are synonymous.

The concept of balance is fundamental to Newtonian mechanics. The definition of the term balance has evolved to encompass a specific set of mechanical laws. Newton's First Law states that when an object is at rest the sum of the forces acting upon it is zero; the forces are "balanced". If the forces become unbalanced, movement will occur.

2.1.2 Balance, Centre of Gravity and Base of Support

Mechanical experimentation has identified that the ability of an object to balance is related to the position of the centre of gravity and the area of the base of support of that object. The centre of gravity (COG) of an object is defined as the single point of an object about which every particle of its' mass is equally distributed. The line of gravity is a vertical line running through the centre of gravity. The base of support (BOS) of an object is the boundary on the support surface that defines the extent of contact between the object and the support surface. If the line of gravity falls within the BOS of the object then the object is balanced. The object becomes unbalanced if the line of gravity is displaced out of the base of support. The relationship between the line of gravity and the BOS of an object is therefore fundamental to the concept of balance. The greater the displacement of the line of gravity before an object becomes unbalanced the greater the stability of that object. Similarly, the greater the external force that can be applied to the object before it becomes unbalanced the greater the stability of that object. If an external force displaces the line of gravity out of the BOS then the object becomes unbalanced and falls. Stability is therefore the inherent ability of an object to remain balanced, and not to fall. Mechanical principals dictate that there is a relationship between the degree of stability of an object and its geometry. Stability increases with a larger base of support, a line of gravity that falls in the centre of the base of support, and a lower centre of gravity.

2.2 Balance in humans

Humans possess the ability to sense stability and instability, and to act to maintain balance and prevent falling. Balance in humans is therefore a more complex issue than the balance of the inanimate objects referred to in Newtonian mechanics. Balance in humans is fundamental to function. King et al (1994) stated that balance was associated with 3 distinct classes of functional ability: (i) the maintenance of postures, such as standing and sitting; (ii) movements which require control of the centre of mass, such as transfers, turning, or reaching; and (iii) the maintenance of the centre of mass over the BOS following destabilising forces, such as trips or slips. Berg et al (1989) similarly identified that there were 3 dimensions to functional balance: "maintenance of posture, adjustments to voluntary movements and reaction to external disturbance".

The term balance is used widely in the clinical field. With reference to balance in humans, Berg (1989) proposed that

> "Balance is a concept. While most therapists have both an intuitive and practical understanding of the term, there is no universal way of defining or measuring it".

Bobath (1978) and Berg et al (1989) used the term balance to refer to the assessment of righting reactions during movement and the quality of the symmetry of postures. This use of the term balance remains common in the clinical field. Ekdahl et al (1989) stated that "there is no adequate consensus regarding how standing balance should be defined". Winter (1995) concurred, stating that "balance is a generic term describing the dynamics of body posture to prevent falling".

For the purposes of this study balance in humans is defined as a multidimensional concept, referring to the reaction of humans during three classes of function; the maintenance of a specified posture, the movement within and between postures, and the reaction to an unexpected disturbance.

2.2.1 Balance and postural sway

The relatively high centre of gravity and relatively small base of support of the human body pose a fundamental problem in the maintenance of stability during upright stance (Winter, 1995; Maki and McIlroy, 1997). Horak (1987) defined unsupported human stance as a form of "unstable equilibrium or balance, because the force of gravity must be counteracted continually by muscular energy". As early as 1862 it was noted that "the body (is) in continuous motion" (Vierorot, 1862 in Thomas and Whitney, 1959). Hellebrandt (1938) concurred with this statement and stated that continuous oscillations occurred during upright stance. Hellebrandt (1938) suggested that standing might be considered as movement upon a stationary base. Since these initial observations a number of studies have used objective measurement systems to confirm that continual small oscillations do occur in upright stance and in other postures and conditions (e.g. Black et al, 1982; Ring et al, 1988; Ekdahl et al, 1989). It has been concluded that "normal standing is not a static posture" (Thomas and Whitney, 1959) and that "quiet standing is a highly dynamic event" (Murray and Peterson, 1973). The continuous motion of the body has been defined as *postural sway*. Postural sway has traditionally been considered as integral to the concept of balance in humans (Ekdahl et al, 1989).

The expressions "static" and "dynamic" are often used in the classification of balance in a clinical setting (Berg, 1989). These terms have been used to describe whether a resultant movement has occurred (dynamic) or not (static). The use of these terms in this context is consistent with the mechanical definition that a body at rest will have a resultant acceleration and displacement of zero; however alternative definitions have also been provided in the literature. Static balance has been defined as the ability of a person to maintain upright stance in a specified position or set of conditions (Patla et al, 1990). Dynamic balance has been defined as the ability to maintain an upright stance when subjected to either an unexpected or continuous disturbance (Mizrahi et al, 1989). This could be interpreted to include continuous dynamic activities such as walking. Mizrahi et al (1989) stated that maintaining upright stance in conditions of dynamic visual disturbance, such as a moving visual scene, was classified as dynamic balance. Berg (1989) suggested that the use of the terms static and dynamic balance were inappropriate as biomechanical descriptors of balance. Berg (1989) identified that the term "static" was misleading, as it ignored the postural sway of the body; and that the term dynamic was too diffuse.

2.2.2 Balance and stability

Mechanical definitions denote stability as a state of balance related to the ability of an object to restore itself to a balance position following an external perturbation. The use of the term stability with reference to human balance is common. Riach & Starkes (1993) stated that:

> "Biomechanically the degree of stability is proportional to the size of the BOS and stability is maximised in any direction when the line of gravity is furthest inside the edge of the BOS".

This definition of human stability is in accordance with the mechanical definitions of the term. However, Lucy and Hayes (1985), Ekdahl et al (1989) and Lehmann et al (1990) described measures of postural sway as being reflective of stability. Di Fabio and Badke (1990) defined an "index of stability", stating that this was equal to the density of the sway path of the centre of pressure. Murray et al (1975) and Dettman et al (1987) defined the phrase "area of stability" as being a measure of the distance that a subject could shift their centre of pressure during stance. McCollum and Leen (1989) defined the same measurement as the "mechanical stability limits", while Riach and Starkes (1993) refer to "stability limits". In contrast, King et al (1994) referred to measurements of the distance that the subject could shift their centre of pressure as the "functional base of support", stating that the functional base of support was reflective of "postural stability".

Murray et al (1975) and Dettmann et al (1987) referred to the measurement of the total excursion of the centre of pressure during quiet stance as a measure of "steadiness". Goldie et al (1989) described measures of force and measures of the centre of pressure during stance as reflective of "steadiness". The term steadiness is not commonly used during mechanical explanation of the balance of objects.

2.2.3 Balance and postural control

Horak (1987) defined "postural control" as "the ability to maintain equilibrium in a gravitational field by keeping or returning the centre of body mass over its base of support". This definition of postural control is comparable with mechanical definitions of stability. However, in addition to the mechanical concept of maintaining the centre of gravity within the base of support, Horak (1987) emphasised that measurement of postural control should consider the "the appropriateness and efficiency of movement strategies used to achieve that equilibrium position". Horak (1987) concluded that

> "Postural control is complex and cannot be evaluated with any global measure of balance".

It has been identified that the principal requirements for the maintenance of postural control (or stability) are the organisation of the sensory inputs and the co-ordination of the output to the muscles (Nashner, 1982; Horak, 1987). Organisation of afferent information from the vestibular, somatosensory and visual systems is fundamental to the maintenance of balance (Berg, 1989). Romberg (1851, 1953, in Samson and Crowe, 1996) derived a classic test which assessed the relative effects of visual inputs on the ability of individuals to maintain equilibrium in an upright posture. Shumway-Cook and Horak (1986) developed a method for altering the sensory input to a subject, using a "sensory-conflict dome" to alter the visual input and foam under the feet to alter the proprioceptive input. The methodology for altering the sensory conditions proposed by Shumway-Cook and Horak (1986) has been used in further research (e.g. Dunn et al, 1991; Cohen et al, 1993; Crotts et al, 1996), as have adaptations of the tests originated by

Romberg (e.g. Briggs et al, 1989; Heltmann et al, 1989; Iverson et al, 1990; Dunn et al, 1991). Many other experiments have been carried out which have manipulated the sensory inputs in the investigation of the nature of human balance.

Although few definitions of the term "postural control" are provided in the literature, and the term is often used synonymously with the terms balance and stability, it is proposed that "postural control" refers to the process of maintaining the body in an upright posture. Thus postural control, or balance control, is exerted over a body in order to maintain or obtain stability. Humans have a number of different postural control strategies that are used to maintain balance.

2.2.4 Strategies of postural control

Research has demonstrated that human balance responses occur with distinct movement strategies (Horak, 1987). It has been identified that generally postural sway and responses to small perturbations of the centre of gravity result in rotation around the ankle joint - an "ankle strategy" (Duncan et al, 1990a). EMG studies have demonstrated that, although the ankle strategy is most common, if there is a narrow support surface or a large perturbation is applied to the subject, movement may occur at the hip joint - the "hip strategy" (Duncan et al, 1990a). If such a great force is applied that the subject is unable to return the centre of gravity to within the base of support using an ankle or hip strategy then the subject may take a step in order to move the base of support under the centre of gravity - this is known as the "stepping strategy" (Duncan et al, 1990a). Although the assumption that the body sways with a distinct strategy has been challenged (Roberts and Stenhouse, 1976), there is now substantial evidence demonstrating that the different strategies are characterised by specific muscle synergies, kinematics and joint torques (Horak et al, 1997).

Maki and McIlroy (1997) described "balance control" as the ability to regulate the relationship between the COM and BOS during activities of daily life. Maki and McIlroy (1997) proposed that a subject has a "combination of reactive (compensatory) and predictive (anticipatory) balance control strategies". Predictive balance control strategies were defined as "minimising the destabilising effect of predictable disturbance due, for example, to voluntary movement". Reactive balance control strategies, which occur in order to maintain stability during unpredictable circumstances, were classified as either "fixed-support" or "change-in-support" strategies. The authors described experimental evidence in support of these classifications. A fixed-support strategy involves the control of the COM over a fixed BOS; the COM can be controlled through the movement of limbs and body segments that are not in contact with the support surface. The ankle and hip strategies (Horak and Nashner, 1986) are examples of fixed-support strategies. A change-in-support strategy involves the control of the BOS to move it under the COM. This could involve stepping or grasping with a hand (Maki and McIlroy, 1997). The stepping strategy, referred to by Duncan et al (1990a), is an example of a change-in-support strategy.

Although postural control strategies have traditionally been considered as reflex-like responses elicited automatically by a sensory stimulus, it is now considered that postural responses to maintain balance are reliant on the assessment and control of many variables by the CNS (Horak et al, 1997). Strategies of postural control therefore vary depending on an individual's goals and environmental context. This view of balance control implies that balance can be considered to be a fundamental motor skill learnt by the CNS (Horak et al, 1997). Thus, like any other motor skill, postural control strategies can become more efficient and effective with training and practice (Horak et al, 1997). Balance control can therefore be regarded as a complex motor skill that is integral to human posture and movement.

2.3 Measurement of balance

Interest in the measurement of human balance originated with the observation of postural sway (Vierorot, 1862, in Thomas and Whitney, 1959). Three principal techniques of measurement were initially adopted in the assessment of postural sway:

"(1) measurement of the displacement of body segments during standing posture, (2) pivot platform measurements of the movement of what was considered the vertical projection of the centre of gravity, and (3) measurement of the muscle activity which controls the inevitable motion of the body". (Murray et al, 1975)

These techniques, which concentrated on the measurement of postural sway during quiet or "static" stance, dominated until the mid 1970s when the recognition that these techniques did not reflect the global nature of balance led to the development of alternative measures of human balance.

Technological advances aided the development of objective measurement systems. It was recognised that the measurements of the "vertical projection of the centre of gravity" were in fact measurement of the centre of pressure (COP). The COP is the centre of the distribution of the total force applied to the support surface. The COP therefore varies with movements of the COG and the muscular forces produced during postural sway. Measurement systems capable of the continuous measurement of the COP, and the vertical forces under the feet, initiated a number of different measurement techniques aimed at the assessment of aspects of balance.

Although technological advances led to the development of sophisticated systems of balance assessment, many of these measurement systems were complex, expensive and laboratory based. The desire for easily administered, less expensive, clinically feasible measurement systems led to the evolution of a number of alternative methods of balance assessment. These principally comprised timed, observational and scored balance tests.

The key methodologies currently used in the investigation of human balance are (1) observational and scored balance tests; (2) timed balance tests; (3) measurements of muscle activity using EMG; (4) measurements of the displacement of body parts; (5) measurements of COP during quiet stance; (6) measurements of COP during weight shifting; (7) measurements of weight distribution.

2.4 Summary and conclusions

Despite the general acceptance that sensory organisation and motor co-ordination are the fundamental requirements for balance (Nashner, 1982; Horak, 1987), no universally accepted biomechanical definitions of human balance are available. The use of the mechanical definitions of balance have been erratic and have proved insufficient for the description of human balance (Berg, 1989).

The observation that the body exhibits continuous postural sway led to an assumption that measures of postural sway were reflective of balance (Berg, 1989). Lichenstein et al (1990) hypothesised that while balance may be a multifactorial concept, deficits in balance may manifest themselves through an increase in postural sway. Although the term stability can be defined by purely mechanical principals, within the literature on human balance "stability" has also been used as a descriptor of aspects of postural sway during quiet stance (Lucy and Hayes, 1985; Ekdahl et al, 1989; Di Fabio and Badke, 1990; Lehmann et al, 1990). In addition the term stability has been used as a reference to the distances that subjects are able to shift the centre of pressure within the BOS (Murray et al, 1975; Dettman et al, 1987; McCollum and Leen, 1989; King et al, 1994).

Balance in humans has been defined as a concept relating to three types of functional activity; the maintenance of a specified posture, the movement within and between postures, and the reaction to an unexpected disturbance. Postural control during the first two of these functions involves predictive balance control strategies, while postural control in the third situation involves reactive control strategies. Balance control can either involve fixed-support or change-in-support strategies. These categories of balance situations and balance control strategies appear to encompass all aspects of balance, whilst acknowledging the multifactorial dimension of the concept balance. Balance control can be regarded as a fundamental motor skill that will be context-specific and will respond to the process of motor learning.

Interest in the field of human balance has expanded over the years and much research has been carried out into aspects of balance, or postural control, in healthy and disabled subjects. The lack of universally accepted definitions of balance, and of any global method of measuring balance (Horak, 1987; Berg, 1989) has led to the development of a variety of systems aimed at assessing different aspects of balance. Seven key methods used in the measurement of balance have been identified:-

1. Observational and scored balance tests;
2. Timed balance tests;
3. Measurements of muscle activity using EMG;
4. Measurements of the displacement of body parts;
5. Measurements of COP during quiet stance;
6. Measurements of COP during weight shifting;
7. Measurements of weight distribution.

Chapter 1 identified that a common aim of physiotherapy treatment for patients with stroke is the improvement of balance during the maintenance of postures such as sitting and standing, during movement within a posture (such as reaching), and during movement between postures (such as rising to stand and sitting down). The following chapter reviews the studies of balance in sitting, standing, reaching, rising to stand and sitting down, with reference to the 7 identified methods of measurement.

3. Studies of balance and sitting, standing, reaching, rising to stand, sitting down and other functional activities

3.1 Balance and sitting

3.1.1 Introduction

A number of studies have investigated various aspects of sitting balance in both healthy and disabled populations. Table 3.1 lists some of the principal studies of balance in sitting. From the table it can be observed that the methods used in the investigation of sitting balance have included observational and scored tests, measurement of the displacement of body parts, measurement of the COP in quiet stance, measurement of the COP during weight shifting and the measurement of weight distribution. No reports of timed tests or measurements of muscle activity using EMG in the assessment of sitting balance were found in the literature. It can be observed from the table that objective measurements have primarily been used in the attempt to identify normal values for samples of healthy subjects and subjects with cerebral palsy or spinal deformities (generally long term wheel chair users). In contrast, studies investigating the relationship between sitting and other functional activities have used subjective methods of measurement, and have generally not involved a sample of healthy subjects in the study. The different methods of assessing sitting balance identified in the table are reviewed in the following sections.

3.1.2 Observational and scored tests of sitting balance

The principal problem with the use of observational and scored tests of sitting balance is the degree of subjectivity involved in the testing and scoring. Sandin and Smith (1990) tested sitting balance using an assessment that involved the subjective observation of a subject's responses to the application of a subjectively applied force. Sandin and Smith (1990) did not address issues relating to the reliability of this assessment tool. Morgan (1994) used an adapted version of the assessment employed by Sandin and Smith (1990). Morgan (1994) tested the inter-rater reliability of the assessment and found it to be high (although the methodology, the number of subjects, and the number of raters, involved in the reliability study are not documented). Both Sandin and Smith (1990) and Morgan (1994) found that there was a strong association between ability of patients with stroke to sit during the first assessment and the ability to walk a number of weeks post-stroke. Thus these studies, despite the low sensitivity due to the scoring of sitting balance, suggest that there is a relationship between sitting balance and functional ability in stroke patients.

Author	Method of measurement	Healthy subjects	Disabled subjects	Principal aims of study
Fife et al (1991)	Observational / scored		CP. n = 40	Normative values
Bohannon et al (1986)	Observational / scored		Hemiplegics. n = 105	Relationships between balance and function.
Keenan et al (1984)	Observational / scored		Hemiplegics. n = 90	Relationships between balance and function.
Morgan (1994)	Observational / scored		Hemiplegics. n = 52	Relationships between balance and function.
Nitz and Gage (1995)	Observational / scored		Hemiplegics. n = 40	Relationships between balance and function.
Sandin and Smith (1990)	Observational / scored		Hemiplegics. n = 24	Relationships between balance and function.
Taylor et al (1994)	Observational / scored		Hemiplegics. n = 8	Relationships between balance and function.
Hulme et al (1987a)	Observational / scored		CP. n = 11	Effect of intervention on balance.
Borello-France et al (1988)	Observational / scored		Hemiplegics. n = ?	Effect of intervention on balance
Millete and Rine (1987)	Measurement of displacement of anatomical points	n = 20		Normative values
Reid et al (1991)	Measurement of displacement of anatomical points	n = 45	CP. n = 8 Head injury. n = 7	Normative values
McClenaghan (1988)	Measurement of the COP during quiet sitting	n = ?	CP. n = ?	Normative values
Fleischer et al (1987)	Measurement of the COP during weight shifting.	n = 16		Normative values
Drummond et al (1982)	Measurement of weight distribution	n = 15	CP / spinal deformities. n = 50	Normative values
Smith and Emans (1992)	Measurement of weight distribution	n = 21	Spinal deformities. n = 79	Normative values
Nichols et al (1996)	Measurement of weight distribution	n = 6	Hemiplegics. n = 12	Relationships between balance and function

Table 3.1: Summary of studies of sitting balance.

The relationship between sitting balance and functional ability in stroke patients has been further investigated in a number of retrospective studies. Nitz and Gage (1995) found a significant relationship between the sitting balance at initial assessment and gait ability at discharge. Keenan et al (1984) found that balance was the most significant factor correlating with gait ability at the time of discharge. Bohannon et al (1986) reported a "significant, but weak" relationship between the side of hemiplegia and the ability to sit independently. However this was not supported by the audit carried out by Nitz and Gage (1995). Although retrospective studies have been used in the exploration of relationships between sitting balance and other variables, the results of all retrospective audits are limited by the reliability of the recorded information. In many cases, factors such as the training and status of the assessor, the frequency of assessment, and the assessors' knowledge and interpretation of the "standardised" assessment is not known. These factors limit the ability to draw firm conclusions from retrospective audits.

Attempts have been made to assess the reliability of subjective measurement tools designed to measure sitting balance. Studies which used photographs to allow repeated observation of subjects have generally demonstrated high reliability (Taylor et al, 1994), while studies that have used direct observation of subjects have demonstrated low reliability (Fife et al, 1991). These results emphasise the difficulty of taking one, effectively "instantaneous", observation of sitting balance as a representation of the sitting balance in general.

3.1.3 Measurement of the displacement of body parts during sitting

There have been few studies that have measured the displacement of body parts to assess sitting balance. Milette and Rine (1987) investigated the head and trunk movement responses of 20 seven-year-old children during induced and self-induced lateral tilt, using a camera and body markers. A number of different body angle measurements were taken from still photographs. Tests of reliability demonstrated good inter-rater reliability ($r > 0.85$). However, all measurements were taken by one tester, yet no tests of intra-rater reliability were reported. The authors stated that the measurements were taken to the nearest five 10^{ths} of a degree and to the nearest 10th of a centimetre. The ability to determine the measurements to this degree of precision must be challenged. Milette and Rine (1987) concluded that the movements of body parts during induced and self-induced lateral tilt were significantly different. Although further studies are required to confirm this conclusion, these results have potential implications for methods of balance testing.

Reid et al (1991) used a 3-D tracking system to measure the movement of C7 during quiet sitting, in healthy children and children with cerebral palsy. The validity of using the movement of only one body part, without reference to movement of other body parts, must be challenged. The reliability of the application of the tracking system and the derivation of the displacement from the recorded data may be low. Further research is required to establish whether the measurement of the displacement of body parts is a valid method of assessing sitting balance.

3.1.4 Measurement of the COP during quiet sitting

Only one study using measurement of the COP during quiet sitting was found in the literature (McClenaghan, 1988). A Kistler force plate, which is commonly associated with studies of stance, was mounted into the seat of a chair to allow subjects to sit directly on the force plate. The position of the subjects was standardised within the anterior-posterior (AP) plane, but not in the medio-lateral (ML) plane; this meant that only data pertaining to the COP in the AP plane could be reported. There were further problems with the subject position, as no force measurements were taken from under the feet or hands; thus the reported force values were not representative of total body weight, or of the total forces applied by the subject. This study highlights that there are several potential problems with the measurement of the COP during sitting, due to difficulties in positioning subjects on the force plate. Further research is necessary to explore the ability to measure the COP during sitting.

3.1.5 Measurement of the COP during weight-shifting in sitting

As in the case of the measurement of the COP during quiet sitting, there are a lack of studies that have investigated weight-shifting in sitting. The one study found in the literature used a specially designed measurement system, consisting of a chair with a central shaft fitted with a series of resistive strain gauges which recorded bending moment, from which the lateral and AP weight displacements were computed (Fleischer et al, 1987). In this study the measurement system recorded over a period of one hour, during which the 16 healthy subjects carried out a hand function task on the table in front of them. Each subject was measured daily for 5 consecutive days. Despite the potential for this measurement system to provide normative values pertaining to sitting balance, the nature of this study meant that the recorded lateral and AP weight displacements were specific to the hand function task carried out and could not be generalised to any other situation. However, the location of the COP over the hour was plotted against time for each test hour, and these image patterns were found to vary characteristically for individual subjects. From this the authors hypothesised that sitting behaviour is controlled by motor programs with different individual characteristics. This hypothesis is therefore of relevance to all studies of sitting balance and movement in sitting. The measurement tool developed by Fleischer et al (1987) could potentially be used for the assessment of specific weight-shifting tasks in order to assess the control of the COP within the BOS.

3.1.6 Measurement of weight distribution in sitting

No studies were found in the literature that reported direct measurements of weight distribution in sitting. It is hypothesised that this is due to the lack of suitable measurement equipment. However, a number of studies have used pressure plates to record the instantaneous pressure distribution under the buttocks in sitting, from which the percentage weight distribution could be derived.

Drummond et al (1982) took objective measurements of the distribution of pressure under the buttocks from 15 healthy children and adults, and 50 patients with cerebral palsy and spinal deformity. The mean percentage weight distribution on the left and right thigh, left and right ischial tuberosity and sacrum are displayed, for the healthy subjects in Table 3.2. It was not stated whether the method of identifying the individual anatomical sections was an automated process or required user-intervention. It was stated that 2 separate tests were performed for each subject and that these were reproducible to within 3%. However it was not made clear whether the whole test was repeated, or whether 2 individual recordings were made during one test session. The latter process would limit the usefulness of the repeated measures, as the subject may not be repositioned between tests.

	left thigh	left ischial tuberosity	sacrum	right ischial tuberosity	right thigh
mean	21	18	5	17	21
standard deviation	4	3	2	7	4

Table 3.2 Mean percentage weight distribution for healthy subjects (n = 15) from the study by Drummond et al (1982)

Smith and Emans (1992) took 3 repeated instantaneous measures of the distribution of pressure under the buttocks in sitting from a sample of healthy subjects (n = 21) and a sample of subjects with spinal deformities (n = 79). Smith and Emans reported that there were no significant differences between the repeated measures for each subject; falsely concluding that the 3 readings were therefore the same. Smith and Emans (1992) determined two main values from the pressure measurements. They stated that

> "The mean of the calculated percentage imbalance was considered to represent the static sitting balance. The sum of the differences from the mean was used to assess the dynamic sitting stability".

The implication from this statement and the ensuing results is, therefore, that the 3 readings were not the same, and that the differences between the readings represent some sort of dynamic balance activity. The results for the healthy subjects were: static sitting balance = 7.1±5.5%; dynamic sitting balance = 12.1±7.6%, calculated from the 3 readings in the method described. From these results the authors concluded that a range of 40 - 60% of weight taken on either side during sitting should be considered normal. However, the results do not appear to support this conclusion. The classification of static and dynamic sitting balance does not appear to be comparable with the other definitions of these terms; dynamic sitting balance, as used in this study would appear to be a measure of sway or variability in movement.

Nichols et al (1996) took direct measurements of the symmetry of weight distribution and ability to weight shift in sitting, from 6 healthy and 12 hemiplegic subjects. The authors adapted a commercially available force platform system that comprised four adjustable force transducers, placing a force transducer under each leg of a standard chair. A standardised protocol was used in an attempt to position each subject on the centre of the chair. Despite the authors' recognition that no data was available in the literature pertaining to the symmetry of weight distribution or ability to weight shift in sitting, Nichols et al (1996) failed to report any data pertaining to these variables. However, the authors did state that there was extremely high test-retest reliability for the healthy subjects (symmetrical sit ICC = 0.86; weight shift to right ICC = 0.87; weight shift to left ICC = 0.92) and moderate to high test-retest reliability for the hemiplegic subjects (during 1st test week, symmetrical sit ICC = 0.18; weight shift to affected side ICC = 0.90; weight shift to unaffected side ICC = 0.87). This study therefore demonstrated that reliable objective measures of weight distribution in sitting can be obtained from healthy and hemiplegic subjects.

Nichols et al (1996) also compared the symmetry and weight-shifting measures with functional tests (the Functional Independence Measure, FIM). No correlation was found between the symmetry of weight distribution in sitting or the ability to transfer weight to the unaffected side and functional ability, and weak correlations were found between the ability to transfer weight to the affected side and functional ability. Each of the hemiplegic subjects were tested on 3 occasions during the period of in-patient rehabilitation. The timing of the tests, or the length of onset after stroke, was not explicit. However, the results demonstrated that there was no change in the symmetry of weight distribution or the ability to weight shift over the period of time, despite in-patient rehabilitation that included the goal of improving the symmetry of sitting (Nichols et al, 1996). The results of this study can thus be argued to highlight issues that are potentially of fundamental importance to the rehabilitation of sitting balance. This study leads to the hypothesis that the symmetry of weight distribution and ability to weight shift in sitting may not be related to functional ability, and may not improve despite therapy aimed at improving sitting balance. This was a small-scale study, limited by a lack of detail pertaining to the measurement system and the absence of reported force or symmetry measures: however, the results emphasise that further research into this area is essential.

3.1.7 Summary and conclusions

Relatively few studies of sitting balance have been carried out, and few firm conclusions can be drawn. The majority of studies of sitting balance have involved observational and scored tests. These tests are useful in the clinical setting and easy to administer, but are limited by the subjective nature of the assessments and the failure of authors to address issues relating to the reliability and validity of the measures. With the exception of the study by Nichols et al (1996), the only studies of sitting balance with hemiplegic subjects found in the literature involved observational scores. Preliminary results have suggested that sitting balance at the time of the first assessment may be related to ability to achieve independent ambulation. Nichols et al (1996) presented results that lead to the hypothesis that the sitting balance of hemiplegic subjects is not related to functional ability and does not improve with therapy.

Very few studies of sitting balance using objective measurement systems have been carried out. The populations studied have primarily been healthy subjects and subjects with spinal deformities. The small number of studies, the sizes of the samples investigated, problems relating to standardisation of position, and the validity of the outcome measures limit the ability to draw conclusions pertaining to the objective assessment of sitting balance. Further research is required to develop systems able to objectively assess sitting balance.

Despite the emphasis on the rehabilitation of sitting balance for subjects with hemiplegia following stroke, there is currently an absence of objective measurements taken from subjects in this population: research into the nature of sitting balance in subjects with hemiplegia following stroke is, therefore, essential. Future studies must use measurements of sitting balance that are precise, accurate, reliable and valid.

3.2 Balance and Stance

3.2.1 Introduction

The early identification of postural sway in stance (Vierorot, 1862 in Thomas and Whitney, 1959) has resulted in a concentration by many researchers on balance in stance. There are therefore many studies pertaining to balance in stance. The 7 principal methods of measuring balance, identified in the previous chapter, have all been regularly used in the investigation of standing balance. With reference to the methods of measurement adopted, Table 3.3 and Table 3.4 identify the key studies that have attempted to determine normative values. Table 3.5 to Table 3.7 list studies which have aimed to find relationships between standing balance and other functional activities, to find relationships between different methods of assessing standing balance, and to investigate the effect of treatment interventions on standing balance. The following sections review these studies with reference to the method of measurement used to assess standing balance.

Observation / scored tests	Timed tests	Measurement of muscle activity using EMG	Measures of displacement of body parts	Measures of COP in quiet stance	Measures of COP during Weight shifting	Measures of Weight distribution
Berg et al (1989) Hill et al (1990) Wolfson et al (1986)	Bohannon et al (1984) Briggs et al (1989) Cohen et al (1993) Crotts et al (1996) Dunn et al (1991) Ekdahl et al (1989) Heltmann et al (1989)	Aniss et al (1990) Badke and Duncan (1983) Dickstein et al (1989) Diener et al (1984) Nashner et al (1979)	Holliday and Fernie (1979) Orma (1957)	Black et al (1982) Bullock-Saxton et al (1991) Hayashi et al (1988) Hellebrandt (1938) Kirkby et al (1987) Lucy and Hayes (1985) Mizrahi et al (1989) Murray et al (1975) Ring et al (1988) Samson and Crowe (1996) Seliktar et al (1978) Thomas and Whitney (1959)	Di Fabio and Badke (1990) Goldie et al (1996) Hayashi et al (1988) King et al (1994) Murray et al (1975) Riach and Starkes (1993)	Bohannon and Tinti-Wald (1991) Bohannon et al (1989) Brownlee et al (1989) Caldwell et al (1986) Dickstein et al (1984) Murray and Peterson (1973) Nichols et al (1995) Sackley and Lincoln (1991)

Table 3.3: Studies aimed at producing normative values, relating to standing balance, for healthy populations.

Observation / scored tests	Timed tests	Measurement of muscle activity using EMG	Measures of displacement of body parts	Measures of COP in quiet stance	Measures of COP during Weight shifting	Measures of Weight distribution
Wolfson et al (1986)	Cohen et al (1993) Heltmann et al (1989)	Badke and Duncan (1983) Dickstein et al (1989)		Lucy and Hayes (1985) Mizrahi et al (1989) Ring et al (1988) Seliktar et al (1978)	Bohannon and Larkin (1985) Di Fabio and Badke (1990) Goldie et al (1996)	Bohannon and Larkin (1985) Bohannon and Tinti-Wald (1991) Bohannon and Waldron (1991) Brownlee et al (1989) Caldwell et al (1986) Dettmann et al (1987) Dickstein et al (1984) Sackley (1991)

Table 3.4: Studies aimed at producing normative values, relating to standing balance, for disabled populations.

Observation / scored tests	Timed tests	Measurement of muscle activity using EMG	Measures of displacement of body parts	Measures of COP in quiet stance	Measures of COP during Weight shifting	Measures of Weight distribution
Hill et al (1996)	Heltmann et al (1989) Iverson et al (1990) Bohannon et al (1993)	Duncan et al (1990)	Pai et al (1994b)	Ekdahl et al (1989) Titianova and Tarkka (1995) Lehmann et al (1990)	Dettmann et al (1987)	Brunt et al (1995) Gruendel (1992) Sackley (1990)

Table 3.5: Studies investigating relationship between standing balance and functional ability.

Observation / scored tests	Timed tests	Measurement of muscle activity using EMG	Measures of displacement of body parts	Measures of COP in quiet stance	Measures of COP during Weight shifting	Measures of Weight distribution
Hamrin et al (1982) Linden et al (1989)				Gauthier-Gagnon et al (1986) Hamman et al (1992) Shumway-Cook et al (1988) Winstein et al (1989)	Hamman et al (1992) Hayashi et al (1988)	De Weerdt et al (1989) Hocherman et al (1984) Wu et al (1996)

Table 3.6: Studies investigating effect of intervention on standing balance.

Observation / scored tests	Timed tests	Measurement of muscle activity using EMG	Measures of displacement of body parts	Measures of COP in quiet stance	Measures of COP during Weight shifting	Measures of Weight distribution
Hill et al (1996)	Bohannon et al (1993)			Duncan et al (1990b) Ekdahl et al (1989) Goldie et al (1989) Lichenstein et al (1990) Mechling (1986) Shumway-Cook et al (1988)		

Table 3.7: Studies investigating relationship between methods of measuring standing balance.

3.2.2 Observational and scored tests of standing balance

Several different balance tests, using a variety of scored outcome measures, have been developed and used in a number of investigations of standing balance. Table 3.8 highlights some of the tests and the outcome measures that have been used.

STUDY	SAMPLE	TEST	OUTCOME MEASURE
Wolfson et al (1986)	21 healthy subjects (38±10years); 18 "non-fallers" (81±9years); 22 "fallers" (84±7years)	Postural Stress Test. Pulley weight system to deliver destabilising force to subject. Subject to remain standing.	1) No. of trials with effective balance (score 0-4). 2) Balance Strategy Score. Evaluation of effectiveness of response; 9 level grading system.
Hill et al (1990)	24 healthy females (over 65years)	Postural Stress Test (Wolfson et al, 1986)	Balance Strategy Score
Hill et al (1996)	41 healthy subjects (72.5±4.1years); 41 hemiplegic subjects (72.5±10.8years)	Step Test for dynamic standing balance. Subject to step foot on and off step as many times as possible in specified time.	Number of steps in time.
Hamrin et al (1982)	37 hemiplegic subjects	Lateral sway, AP sway and AP weight shifting recorded on force plate	Score, obtained from force plate measurements (score 1-3).
Berg et al (1989)	14 videos of patients, assessed by 5 raters	Questionnaire	Score from questionnaire responses

Table 3.8: Observational and scored tests of standing balance.

One of the most well used scored balance tests was developed by Wolfson et al (1986). This test is known as the Postural Stress Test (PST) and uses a pulley weight system to deliver reproducible impulses of destabilising force to a subject. Wolfson et al (1986) developed two measures of the subjects balance responses. One of these measures was simply the number of trials with effective balance - scores of 0, 1, 2 or 3 depending on whether if balance was retained during the different destabilising forces. The second measure was named the "Balance Strategy Score" (BSS) and was an evaluation of the effectiveness of the balance response, using a 9 level grading score. The inter-rater reliability of 4 health professionals, observing videos of the responses of 20 hemiplegia subjects, was high (Cronbach's Alpha = 0.99). Wolfson et al (1986) then tested the PST with 21 young healthy subjects, 18 healthy elderly subjects, and 22 subjects with a history of falling. The correlation between the number of trials with effective balance and the BSS was found to be high ($p<0.001$).

Hill et al (1991) used an adapted version of the PST, to assess the balance of 24 healthy females. This study demonstrated that there were no significant differences between the BSS from tests on different days, suggesting that the BSS had high intra-rater reliability. The authors concluded that the BSS, as measured during the PST, was a reproducible measurement of responses to a perturbation of balance in a homogenous sample of healthy elderly females. However, the authors did warn that the high intra-rater reliability might have been partly due to the low inter-subject variation.

Wolfson et al (1986) and Hill et al (1991) have therefore demonstrated that the PST and the BSS may provide a reliable measurement of standing balance. However the validity of this test as a measurement of standing balance has not been addressed. Further research is required to explore the use of this test. Problems with the determination of a valid score of standing balance are common to many of these studies. Berg et al (1989) developed a scored questionnaire based on items which health professionals assess pertaining to balance, and assumed that this would provide a valid measure of balance. However this is based on the supposition that the clinical assessments and perceptions pertaining to balance of health professionals are valid.

Hill et al (1996) attempted to develop a specific and valid test of dynamic standing balance. The test involved stepping with a specified foot (both right and left were tested) on and off a 7.5cm or 15cm block as many times as possible in 15 or 30s. The validity of the Step Test was investigated by testing 29 healthy subjects and 20 hemiplegic subjects using the step test, the test of functional reach developed by Duncan et al, 1990b (see section 3.3.4), measures of comfortable gait speed and stride length. The step test was found to correlate with gait velocity and stride length ($p<0.001$). From these results Hill et al (1996) concluded that the Step Test was a valid test of standing balance. However the finding that the Step Test correlated with gait velocity and stride length, but not with functional reach, which Duncan et al (1990b) proposed as a test of balance ability, suggests that the Step Test is not a valid test of dynamic standing balance, although it may be a valid test of gait ability.

Hamrin et al (1982) assigned a ranked score to quantitative platform measures. Lateral sway, AP sway and AP weight shifting were recorded using force plates. Following the recording of the objective measurements a score of 1-3 was assigned, from the platform measures. The method of ranking the quantitative force measures to scores of 1-3 was not explained. The authors did not address issues relating to this choice of balance scoring, and the reasons for using a sensitive objective measurement tool to obtain an estimation of standing balance were not stated. This methodology appears to lose the advantages and sensitivity of the objective test, without gaining the advantages of the ease of administration and lack of sophisticated equipment required for subjective tests.

In summary, a number of different observational and scored tests of standing balance have been developed. The advantages of observational and scored tests are often that they do not require the use of sophisticated equipment, and are easy to administer. However a number of the scored tests of standing balance have required the use of specialised equipment such as pulley systems (Wolfson et al, 1986; Hill et al, 1990) and force plates (Hamrin et al, 1982). The reliability of many of these tests has been investigated, and demonstrated to be high (Wolfson et al, 1986; Berg et al, 1989; Hill et al, 1991, 1996), although these findings must be interpreted with care as the number of subjects and testers have generally been low. The high reliability found in these studies could be due to the lack of sensitivity and distinctiveness of observational and scored tests. The greatest limitation of many of these tests is that the validity of the score as an assessor of standing balance has not been determined.

3.2.3 Timed tests of standing balance

Table 3.9 describes the most commonly used timed tests used in the more recent studies of standing balance.

STUDY	SAMPLE	STANCE CONDITIONS	TIMED TEST
Bohannon et al (1984)	184 healthy subjects (20-79years)	Feet apart (26cm), feet together, one-legged stance + eyes open and closed	Ability to maintain position, up to a maximum of 30s. Best of 5 attempts
Bohannon et al (1993)	38 hemiplegic subjects (30-88years)	Feet apart (foot length), feet together, one-legged stance	Attempt feet apart stance - if maintained for 60s, proceed to feet together stance - if maintained for 60s, proceed to one-legged stance. If 60s not achieved, have 5 timed trials at that level.
Briggs et al (1989)	71 healthy women (60-86years)	Heel-to-toe stance, one-legged stance + eyes open and eyes closed	Ability to maintain position, up to maximum of 45s for one-legged stance, and 60s for heel-to-toe stance
Cohen et al (1993)	15 healthy subjects (25-44years); 15 healthy subjects (45-64years); 15 healthy subjects (65-84years); 15 subjects with vestibular disorders (30-87years)	Feet together stance + 6 sensory conditions proposed by Shumway-Cook & Horak (1988)	Ability to maintain position, up to a maximum of 30s
Crotts et al (1996)	15 healthy subjects (23-37years); 15 professional dancers (20-32years)	One-legged stance + 6 sensory conditions proposed by Shumway-Cook & Horak (1988)	5 trials of attempting 30s. Perfect score (i.e. 30s) on 1st trial = 5points*30s (=150); on 2nd = 4points*30s+time from 1st trial etc.
Dunn and Prewitt (1991)	90 healthy subjects (50-79years)	Feet together stance, heel-to-toe stance + 6 sensory conditions proposed by Shumway-Cook & Horak (1988)	Ability to maintain position, up to a maximum of 60s
Ekdahl et al (1989)	152 healthy subjects (20-64years)	One-legged stance + eyes open and eyes closed	Ability to maintain position, up to a maximum of 30s + time able to maintain one-legged stance, eyes closed
Heltmann et al (1989)	113 healthy women	Heel-to-toe stance, one-legged stance + eyes open and eyes closed	Ability to maintain position, up to maximum of 30s for one-legged stance, and 60s for heel-to-toe stance
Iverson et al (1990)	54 healthy males (60-90years)	Heel-to-toe stance, one-legged stance + eyes open and eyes closed	Ability to maintain position, up to maximum of 30s for one-legged stance, and 60s for heel-to-toe stance

Table 3.9: Timed tests of standing balance

The majority of the studies using timed tests of standing balance have been carried out with healthy subjects, in an attempt to assess the influence of different sensory conditions on ability to maintain balance. Many of these studies have used standardised feet positions that are aimed at decreasing the base of support and consequently reducing the ability to balance. The reason for attempting to reduce the base of support is that, unlike measurements of postural sway and weight distribution which can determine subtle differences in normal foot-apart stance, timed tests require stance positions which provide a greater challenge to balance. The use of timed tests can be argued to be advantageous due to the lack of equipment required, the ease in which the tests can be carried out, and the validity of using measures of time.

Many timed tests of standing balance have involved the subject attempting to maintain a specified standing posture (these postures are identified in Table 3.9) for a maximum length of time. The maximum times selected have included 30 seconds (Bohannon et al, 1984; Cohen et al, 1993), 45 seconds (Briggs et al, 1989), and 60 seconds (Heltmann et al, 1989; Iverson et al, 1990; Dunn and Prewitt, 1991). In all of these studies the use of the arbitrarily selected maximum time has resulted in a ceiling effect, with the majority of subjects achieving the maximum stance time. This provides results that lack distinctiveness. Despite the number of studies that have demonstrated the limitations associated with the selected maximum times, no appropriate timed-test appears to have been determined. Ekdahl et al (1989) used the traditional 30 second maximum in the assessment of one-legged stance. However, in addition to this, this study also recorded the maximum time for which one-legged stance with eyes closed could be maintained, with no cut-off time. The subjects tested were 152 healthy adults, aged between 20 and 64 years. All of the subjects aged 54 and below (n=109) were able to maintain the eyes-open one-legged stance test for the full time of 30 seconds. The use of a test of maximum stance time would, therefore, appear to be a more distinctive test of balance ability.

Crotts et al (1996) attempted to use a timed test to develop a balance "score". However the scoring system made assumptions regarding learning and variability in balance ability, assuming that if a subject achieves 30 seconds stance in the first trial then they will also achieve 30 seconds in all subsequent tests. There is no evidence to support this assumption; this score therefore lacks the advantages of the validity associated with timed tests.

Few studies have addressed the reliability of the use of timed tests. Bohannon et al (1993) investigated the reliability of timed tests, with a sample of hemiplegic subjects. Repeated test on two different days demonstrated that the measures of balance time were not reliable within or between sessions. The lack of reliability, validity and distinctiveness of these tests presently outweigh the advantages associated with the ease of administration. Further research is necessary into the methodology of the timed tests before they can become a useful aid to assessment of standing balance.

3.2.4 Measurements of muscle activity using EMG during stance

A large number of studies have recorded muscle activity using EMG to assess postural sway in healthy subjects and in hemiplegic subjects. Many of these experiments have used the application of an external force to induce a perturbation in the subject, and have recorded the muscle activity subsequent to the perturbation. The results of each of these studies are specific to the muscle groups tested and to any external force applied. Duncan et al (1990a) took EMG recordings from 17 healthy subjects (60-79 years) in order to compare the Postural Stress Test (Wolfson et al, 1986), which involves applying increasing destabilising forces to the waist, with a platform perturbation test. The results demonstrated that there were some distinctions between the muscle response patterns for the two tests, although there was variability in the response patterns for both tests. The authors concluded that balance responses were specific to the methods of perturbation.

The specificity of EMG studies, to both the muscle group tested and to the method of perturbation used, limits the ability to use muscle activity recordings as valid and generalisable assessors of global ability to balance.

3.2.5 Measurement of the displacement of body parts during stance

Measurement of the displacement of body parts in the assessment of postural sway during stance was popular prior to the increased availability of force plates capable of directly measuring COP movement. Orma (1957) used photographs of an illuminated point on subjects' heads in order to determine the magnitude of postural sway. Holliday and Fernie (1979) used potentiometric displacement transducers in the sagittal and coronal planes in order to assess movement of the pelvis in the horizontal plane. Measurements of the displacement of anatomical points have also been used to assess movement of body parts in response to a static destabilising force (Lee et al, 1988). However the application of destabilising forces will result in responses related to strength and power, and might not be reflective of balance.

Pai et al (1994b) used a motion analysis system (WATSMART) comprising infrared LEDs and a camera system to record the locations of the joint centres of the ankles, knees, hips and shoulders during lifting one leg off the floor. This information was then used to compute the location of the COM of the whole body, with respect to the

BOS. 14 subjects with hemiplegia took part in the study. Pai et al (1994b) discussed the results with reference to the movement of the centre of mass in respect to the BOS. This study thus demonstrated the potential usefulness of motion analysis in the investigation of standing balance. However, the measurement of the displacement of anatomical points in the determination of the position of the COM is limited by the inability to record the movement of all relevant joints, the necessity of using estimates of the mass and COM of different body segments, and the ensuing uncertainty in estimating the location of the COM.

3.2.6 Measurements of the COP during quiet stance

The measurement of postural sway, by measuring the movement of the COP has been carried out with subjects in stance since the early work of Hellebrandt in 1938. Hellebrandt (1938) constructed and calibrated a series of platforms that could measure the COP in the AP and lateral planes. Measurements were taken from 10 healthy women, and it was concluded that the COP shifted incessantly although the movement might be less than 1cm. This was a pioneering piece of investigative work for this time and, although the lack of standardisation of measurement made comparison with later studies impossible, this work initiated the study of the movement of the COP in stance.

Thomas and Whitney (1959) produced a measurement platform that was more objective than the platforms used in earlier experiments. This measuring platform, comprising a suspended platform with "elastic restraining systems" at the corners connected to a Wheatstone bridge circuit, was capable of continuous data collection. Thomas and Whitney (1959) used this system to record 4 minutes of standing data from 10 healthy men (aged 19-20years). The results of this study identified that the mean amplitude of the COP in the AP plane varied from 0.36-1.13cm. The authors did not state the frequency at which the data was collected; the frequency of data collection has implications, as the frequency of postural sway was not known. The use of a measuring frequency lower than that of postural sway may have affected the range of results measured.

Murray et al (1975) measured the position of the COP, using a specially designed force platform, from 8 men in each of the 3rd, 5th, and 7th decades during single- and double-limb stance over a 1 minute period. The authors concluded that the mean position of the COP in the AP plane during double limb stance was (in cm) 0.33±0.08, 0.38±0.08, and 0.41±0.08 for the 3 decades. The use of a different measurement outcome than had been used in the previous study by Thomas and Whitney (1959) makes it impossible to compare the results of the 2 studies. In addition, the failure of the authors to state whether the standing posture adopted by the subjects was standardised or not, makes it impossible for this study to be repeated by other researchers.

The two problems highlighted in the study by Murray et al (1975) - the use of different measurement outcomes from previous studies, and the failure to standardise the testing methodology and procedures - have continued to arise in the majority of further studies using measurements of postural sway in stance. Table 3.10 highlights the different outcome measures which have been used during studies of standing balance, which have used force platforms to record the movement of the COP. For many of these studies no explanation pertaining to the selection of the outcome measure is provided; it is generally assumed that the selected outcome measure is reflective of standing balance. Table 3.11 lists some of the testing protocols, including the time and frequency of measurement, and the standardisation of the standing position during testing, which have been used in different studies of the movement of the COP during stance. The use of different outcome measures and testing protocols makes comparison between studies difficult.

STUDY	SAMPLE	OUTCOME MEASURE
Black et al (1982)	132 healthy subjects (20-49years)	mean squared displacement of centre of force
Bullock-Saxton et al (1991)	15 males, 15 females (17-25 years)	resultant movement of COG
Gauthier-Gagnon et al (1986)	11 below-knee amputees (65±11years); 30 healthy subjects (60±9years)	mean position of COP. mean area of sway.
Goldie et al (1989)	28 healthy subjects	force and COP measures
Hamman et al (1992)	17 healthy subjects (20-35years)	area of sway
Jeong (1991)	10 healthy men (23-26years)	total sway distance total AP distance total ML distance
Karlsson (1997)	20 healthy subjects. 20 hemiplegic subjects.	standard deviation of AP ground reaction force divided by body mass standard deviation of AP COP measures
Kirkby et al (1987)	5 healthy men; 5 healthy women (26.4±6.2years)	total excursion of COP, in AP and ML directions. mean AP and ML position as a %age of distance from midline.
Lehmann et al (1990)	34 healthy subjects (16-30years). 46 head injured.	mean COP position mean displacement sway path sway area.
Lichenstein et al (1990)	43 females (over 65years)	XY area = = (range of movt along x-axis * range of movt along y-axis)/time of trial radial area = radial distances of centre of force at each sample from geometric centre of stance, averaged to determine average radial area - adjusted for time as XY area average velocity = average of instantaneous velocities
Lucy and Hayes (1985)	66 healthy subjects (30-80years). Subjects with cerebellar ataxia.	mean position of COP. average RMS for amplitude of sway in AP and ML directions.
Mizrahi et al (1989)	6 healthy subjects (64.6±8.1years). 16 hemiplegic subjects (60.9±10.5years)	relative sequence of force vector on feet timing and amplitudes of waveforms force activity (WBI = good-hemi/total)
Murray et al (1975)	8 healthy men in each of 3rd, 5th & 7th decades	mean position of COP average distance of COP from mean position total excursion of COP in AP and lateral planes vertical force fluctuations
Ring et al (1988)	27 "recent fallers" (65-86years); 15 "remote fallers" (65-82years); 20 "non fallers"(65-79years)	max amplitude of AP sway total distance of COP in AP direction (AP sway) logarithm of AP sway.
Rode et al (1997)	15 healthy subjects (28-72years); 30 hemiplegic subjects (21-70years)	total sway area mean COP position in AP plane mean COP in ML plane
Samson and Crowe (1996)	"about 30" healthy subjects (20-60years)	mean excursion of COP
Seliktar et al (1978)	21 healthy subjects; 18 hemiplegic subjects; 27 head-injured subjects.	frequencies identified -1) "tremor", 1-8 cycles per sec, 2) "ataxia", 0.1-1 cps, 3) "sway", 0.03-0.0025 cps. co-ordinates of vertical forces, and COP of each foot. F1/F2, or Fa/Fu
Shumway-Cook et al (1988)	16 hemiplegic subjects (66±6years); 34 healthy subjects	lateral displacement total sway area.
Thomas and Whitney (1959)	10 healthy men (19-20 years)	mean amplitude of COP in AP plane
Titianova and Tarkka (1995)	20 hemiplegic subjects (33-77years); 20 healthy subjects (29-67years)	mean displacement of COP in AP and ML planes.
Winstein et al (1989)	42 hemiplegic subjects	mean COP position

Table 3.10: Outcome measures used in studies measuring COP movement during stance.

STUDY	feet position	arm position	shoes on / off	time	frequency	number of repetitions
Black et al (1982)	s t	j	off	15s	5Hz	2
Bullock-Saxton et al (1991)	y	ns	ns	60s	ns	1
Ekdahl et al (1989)				30s	10Hz	1
Gauthier-Gagnon et al (1986)	a	h	ns	15s	20Hz	1
Goldie et al (1989)	a w t	ns	ns	32s	40Hz	1
Hamman et al (1992)	ns	ns	ns	20s	20Hz	1
Jeong (1991)	s	h	ns	20s	25Hz	2
Kirkby et al (1987)	a s	ns	off	20s	100Hz	1
LaPier et al (1997)	r	h	off	20s	20Hz	1
Lehmann et al (1990)	s a t	ns	ns	22s	50Hz	2
Lichenstein et al (1990)	c	ns	ns	up to 10s	50Hz	2-4
Lucy and Hayes (1985)	ns	ns	ns	20s	ns	1
Mechling (1986)	ns	ns	ns	n/a	n/a	n/a
Mizrahi et al (1989)	a	ns	on	60s, mid 40s used for analysis	ns	2
Murray et al (1975)	ns	ns	ns	60s	ns	2
Ring et al (1988)	ns	ns	ns	16s	ns	1
Samson and Crowe (1996)	s t	j h	ns	60s	25Hz	5-10
Seliktar et al (1978)	c	ns	ns	ns	ns	ns
Shumway-Cook et al (1988)	a	ns	ns	30s	33Hz	2
Thomas and Whitney (1959)	ns	ns	ns	4 min		2
Titianova and Tarkka (1995)	a	ns	ns	51.2s	40Hz	3
Wade et al (1997)	a w t	h	off	10s	100Hz	3
Winstein et al (1989)	c	ns	ns	30s	10Hz	1

Table 3.11: Subject position and testing protocol for studies of standing balance using measurement of COP movement.

feet position: c = comfortable stance; a = feet apart, but in standardised position; s = feet together, with no space between; t = tandem stance (one foot immediately in front of other); w = step stance (one foot stepped forward as if to walk); r = feet position relative to subject's height.

arm position: h = arms hanging freely by side; j = Jendassic manoeuvre (fingers clasped together at chest height, arms pulling against each other maximally; a position aimed at stabilising upper body movement).

ns = not stated. n/a = not applicable.

The validity of the different outcome measures as assessors of balance remains unknown, and many authors fail to provide evidence pertaining to the choice of outcome measure. Black et al (1982) stated that the mean squared value of the displacement of the COP was selected as this was proportional to energy expenditure. If the reported measure is representative of energy expenditure (and the failure of the authors to provide evidence of the relationship between energy expenditure and the mean square value challenges the validity of this assumption) it is questionable whether the measure is also reflective of standing balance. Hamman et al (1992) investigated the effect of dynamic balance training exercises on the area of sway in quiet stance, and concluded that there was no relationship between balance during static and dynamic stance. This opposes the common assumption that measures of postural sway during quiet stance are reflective of a more general ability to balance. However, it could be argued that had the authors examined parameters other than the area of sway the outcome might have been different. In addition, the authors failed to consider that the lack of change in the measured outcome might have occurred due to the failure of the training programme to have a training effect.

Ekdahl et al (1989) recorded a number of different COP measures and a number of functional tests, with 152 healthy subjects. The results demonstrated a high correlation between the COP measures and the functional tests. However, although the authors investigated the test-retest reliability of the COP measurements, the intra-rater and inter-rater reliability and issue of blindness for the other measures were not addressed. In contrast, Titianova and Tarkka (1995) found that there was no relationship between measures of gait velocity and measures of COP in stance. Lichenstein et al (1990) investigated the relationship between COP measures of standing balance and the clinical mobility index (Tinetti, 1986), which includes a scored scale of balance and gait, in 43 healthy elderly females (over 65years). "Modest" correlations were found between the COP measures and the mobility index scores and the authors suggested that the two techniques might be assessing different components of balance. Lichenstein et al (1990) hypothesised that there may be no relationship between the static tests of standing balance and the "performance based", or dynamic, assessment of the mobility index. Winstein et al (1989) investigated measures of standing balance and gait performance in subjects with hemiplegia, and found that the mean COP position in stance was not related to temporal measures of gait performance and vertical force measures of cane support during gait. These studies highlight that the validity of COP measures in the assessment of balance is not known.

The validity of magnitude of sway as a measure of balance ability was challenged by Gauthier-Gagnon et al (1986). Gauthier-Gagnon et al (1986) recorded the mean position of the COP and the mean area of sway, using a standardised testing protocol, in a sample of 30 healthy subjects, and 11 unilateral below-knee amputees. The results demonstrated that the healthy subjects had a mean area of sway that was significantly larger than that of the amputees. A large intersubject variation (over 100% for healthy subjects; over 200% for amputees) reduces the conclusions which can be drawn from these results. However these results do question the assumption that greater balance is identified by a decrease in the movement of the COP. One possible explanation, which is proposed by the authors, is that the decrease in the postural sway in subjects with amputations is related to the mechanical limitations of the prosthesis, rather than any direct change in ability to balance. However, in view of the decrease in proprioception due to the amputated limb, these findings are surprising.

A number of studies have investigated the test-retest reliability of COP measurements of standing balance. Using a variety of outcome measures, these studies have found that the variation in repeated tests from an individual is similar to the group variation (Black et al, 1982; Samson and Crowe, 1996). Samson and Crowe (1996) suggested that this variation means that repeated tests from an individual would be of limited use. However, although this conclusion would appear to be valid in the context of repeated tests from an individual, it could be argued that if the tests on the individual were assessed relative to a group of individuals, tests out of the group range would identify abnormal results.

Kirby et al (1987) identified that the use of different standing positions by different researchers made it difficult to draw conclusions pertaining to the nature of standing balance and postural sway. This identification led to a study aimed at investigating the effects of foot position on COP measurements. 5 men and 5 women were tested using a Kistler force plate, standing with 4 different mediolateral foot positions, 5 different AP foot positions, and 5 different angles of the feet relative to each other. Kirby et al (1987) elected to investigate the total excursion of the COP in the AP and lateral directions during the 20 seconds of data collection, and the mean AP and lateral position of the COP expressed as a percentage of the distance from the midline of the right to the left foot, and from the heels to the toes. However the authors did recognise that there was no evidence for the selection of these parameters in preference to other COP measures, such as the shape of the COP path or the frequency of sway. The results demonstrated that there were significant differences between the outcome measures during different foot positions ($p<0.05$). It was found that increasing the mediolateral dimension of the BOS above a certain size did not effect the magnitude of the lateral sway; this challenges the assumption that mediolateral sway is a valid measure of ability to balance. The results of this study have implication both for future research and for the interpretation and comparison of other studies. LaPier et al (1997) identified that postural sway was related to body height, and used a foot position relative to body height in order to eliminate the effect of differences in height.

McIlroy and Maki (1997) highlighted that while several studies utilised standardised foot placement during balance testing, the choice of standardised placement was often not consistent between studies and was generally arbitrarily selected. Maki and McIlroy proposed that a suitable standardised position may be the average position adopted by several subjects. Investigation led to the conclusion that there was a wide variation in the preferred foot placement of subjects, with statistically significant differences between young and elderly subjects ($p<0.001$). This variation between subjects highlights the potential differences in balance ability that may occur as a consequence of different standing positions. The effects of different standing positions must be addressed in all studies of standing balance, regardless of the method of measurement.

In addition to the different subject positions potentially affecting the measured outcome, and preventing comparison between studies, the accuracy, precision and reliability of the methods of standardising the position may be low in many studies. For example, Bullock-Saxton et al (1991) stated that the subjects were positioned on the force platform so that their COG fell through the centre point of the force platform. It is not explained how the COG was determined or how this procedure was carried out; the nature of postural sway, and the resultant movement of the COP and COG would make it difficult to do this with any degree of accuracy, precision or reliability. Furthermore, the accuracy, precision and reliability of measurement tools, and the methods of deriving the measured outcome from the measurement tools, are inadequately addressed or determined in many studies.

Jeong (1991) identified a further potential influence on measures of COP that has rarely been addressed in studies of human balance. Jeong (1991) assessed the effect of respiration rate on the sway distance of 10 healthy subjects, and found that changes in the respiration rate significantly effected postural sway ($p<0.01$). Further exploration is required to see whether the effects of natural differences in respiration rate could alter the results of studies of postural sway. The influence of respiration rate on postural sway potentially limits the reliability of studies using COP measures.

Several studies have demonstrated that parameters relating to COP measures during stance in hemiplegic subjects are significantly different from healthy subjects. Seliktar et al (1978) took measurements from 21 healthy subjects and 18 hemiplegic subjects, and concluded that the hemiplegic subjects demonstrated greater amplitude and frequency of sway than healthy subjects. This study did not take variables such as age and the case history of the subjects into account, which limited the conclusions that could be drawn. Mizrahi et al (1989) demonstrated that the mean amplitude of sway was significantly different in hemiplegic subjects and healthy subjects ($p<0.01$). The total sway activity (expression of vectorial summation of absolute horizontal forces on both legs) was significantly higher for the hemiplegic subjects than the healthy subjects. The results of this study are limited by the low number of subjects (only 6 healthy subjects, and 16 hemiplegic subjects) and the failure to adequately standardise the foot position during testing ("about 30cm" and a "slight angle" between the feet). However, the results of the study by Shumway-Cook et al (1988), using a larger sample of healthy subjects (16 hemiplegic subjects and 34 healthy subjects) concurs that COP measures are different in healthy and hemiplegic subjects.

Despite the popularity of the use of measures relating to the COP to assess standing balance, the validity of these measures has not been demonstrated. Winter (1995) identified that there was considerable confusion regarding the interpretation and analysis of measures of the COP. Newell et al (1993) suggested that it was common for researchers to assume that the variability in the mediolateral and anterior-posterior displacement of the COP was a valid measure of postural stability. However, detailed exploration of the variability of data relating to COP dimensions, from 12 healthy subjects and 24 subjects with dyskinesia, suggested that traditional COP measures may not be valid assessors of balance. Newell et al (1993) concluded that measures of the variability of the COP were "not a *sufficient* measure of stability". Wade et al (1997) assessed postural sway and functional ability in subjects with traumatic brain injury. This study concluded that there was no relationship between any measures of functional ability and measures of the COP. This challenges whether COP measures are related to functional ability in this patient group.

In summary, although there have been many studies that have measured variables relating to the COP during stance the validity of these measures as assessors of standing balance has not been demonstrated. The use of different variables and different testing protocols limits the ability to draw conclusions from these studies. Further research into the nature of different variables of the COP should be carried out before measures of the COP are used in the assessment of standing balance.

3.2.7 Measurement of COP during weight-shifting in stance

A number of studies have taken measurements of weight shifting activities in an attempt to quantify balance in stance. Table 3.12 lists some of the key studies.

STUDY	SAMPLE	WEIGHT SHIFT	OUCOME MEASURE
Dettmann et al (1987)	15 hemiplegic subjects (46-87years)	maximum forwards, backwards, left and right lean, sustained for 15s	percentage of BOS over which COP moved during weight shifting
Di Fabio and Badke (1990)	5 healthy subjects (52±17years); 6 hemiplegic subjects (59±18years)	maximum forwards, backwards, left and right lean, repeated 5 times. Shifting weight as rapidly as possible to target at 50% of maximum forwards, backwards, left and right lean	density of sway data points around the geometric centre of the sway path, during shifting to 50% of maximum lean. Intensity of body sway with respect to frequency of motion
Goldie et al (1996)	20 healthy subjects (51.6±18.4years); 20 hemiplegic subjects (50.7±18.5years)	maximum forwards, backwards, left and right lean, sustained for 5s	mean position of COP during forwards, backwards, left and right lean, with reference to limits of BOS
Hayashi et al (1988)	10 healthy men (21-31years)	maximum forwards and backwards lean, whilst standing in "forward bent position"	maximum displacement of COP in AP plane
King et al (1994)	113 healthy subjects (20-91years)	maximum forwards and backwards lean, sustained for 8s	AP distance between mean COP positions in leaning
Liston and Brouwer (1996)	20 hemiplegic subjects (64.0±8.5years)	randomly to highlighted targets, using computerised COP feedback. Targets at 75% of limits of stability.	average time and sway path
Murray et al (1975)	8 healthy men in each of 3rd, 5th & 7th decades	maximum sustained forwards, backwards, left and right lean	distances between sustained positions as percentage of AP and ML dimensions of BOS
Riach and Starkes (1993)	70 healthy children (4-14years); 17 healthy adults (18-27years)	maximum forwards and backwards lean, sustained for 2-3s	distances between sustained positions as percentage of AP and ML dimensions of BOS

Table 3.12: Outcome measures used in studies measuring weight shifting during stance.

In order to measure the movement of the COP during weight shifting activities it is necessary to use force plates that are capable of continuous measurement of the COP position. Murray et al (1975) first introduced the measurement of weight shifting during the assessment of the standing balance of healthy men. Many of the later studies of weight shifting also incorporated a measurement of the COP during quiet stance (Dettmann et al, 1987; King et al, 1994; Goldie et al, 1996). The points discussed relating to the precision, accuracy and reliability of the measurement systems used in the assessment of movement of the COP in quiet stance (section 3.2.6) have the same implications for the studies of weight shifting. The calibration of the measurement systems is inadequately addressed in many of these studies. The majority of the studies of weight shifting use similar methodologies. Murray et al, 1975; Dettmann et al, 1987; and Goldie et al, 1996 all assessed the maximum sustained weight shifting in the forwards, backwards, left and right directions. Hayashi et al, 1988; Riach and Starkes, 1993; and King et al, 1994 all measured the maximum weight shifting in the forwards and backwards directions, but omitted to assess the shifting in the left and right directions.

The use of the maximum amount of weight shifting could potentially introduce errors into these studies. Achievement of a maximum amount of weight shifting will be related to the subjectivity of the perceptions of the maximum by each individual subject. King et al (1994) got each subject to practice weight shifting, without bending the hips or knees and keeping the arms at the sides, until they were observed to be performing the task "correctly". The subjectivity of the assessment of "correct" is not addressed. Riach and Starkes (1993) asked the subjects to sway as far as possible, without placing any restrictions on the movement. Goldie et al (1996) asked the subjects to lean forwards and backwards from the ankles; but requested subjects to "shift the hips and shoulders to the left and right" in order to stimulate lateral weight shifting. It is perceivable that different subjects could interpret these commands in different ways. Goldie et al (1996) did not state whether any form of correction was given to subjects if they moved in a way other than the tester anticipated. Liston and Brouwer (1996) asked subjects to achieve 75% of their maximal weight shifting, using a computerised feedback system to provide subjects with information pertaining to the movement required and the position of the COP. This system had the advantage that the errors between the executed and the intended movement could be determined in addition to variables pertaining to the COP movement. Hayashi et al (1988) attempted to ensure that all the sway occurred at the ankles, by getting the subjects to stand with the hips bent and the knees locked in extension. The use of this position meant that Hayashi et al (1988) assessed a different function than other studies, and the results of this study cannot be compared with other studies. Hayashi et al (1988) did not address issues relating to the differences in balance control which might have occurred as a result of this position, which would cause the COG to move anteriorly.

The majority of these studies report outcome measures relating to the distance that the COP moves in the AP or lateral plane during the weight shifting activity. A number of studies report this as a distance of movement (e.g. Hayashi et al, 1988; King et al, 1994; Goldie et al, 1996). Since ability of an object to balance is related to the size of the base of support, even if the studies use a standardised foot position, the size of subjects' feet will alter the base of support and this could potentially influence the weight shifting measurements. A number of studies have taken the size of the BOS into account, and have expressed the position of the COP during weight shifting as a percentage of the BOS (Murray et al, 1975; Dettmann et al, 1987; Riach and Starkes, 1993). Mechanical definitions of balance demonstrate that ability to maintain balance is related to the height of the COG, in addition to the size of the BOS. No published studies investigating weight shifting appear to have identified the influence of height, weight, or position of the COG on weight shifting ability.

Studies comparing the weight-shifting ability of healthy subjects and subjects with hemiplegia have demonstrated that hemiplegic subjects are less able than healthy subjects to displace their COP within the BOS (Murray et al, 1975; Goldie et al, 1986). In addition, hemiplegic subjects demonstrate significantly more weight shifting to the unaffected side than to the affected side (Goldie et al, 1986). Dettmann et al (1987) found that the weight distribution during quiet stance by 15 male hemiplegic subjects correlated significantly with the position of the COP during lateral weight shifting. Dettmann et al (1987) reported a number of correlations between measures of weight shifting and temporal measures of walking performance, and between balance measures and the functional scores. The validity of the weight-shifting as an assessor of balance is further supported by Liston and Breuwer (1996) who assessed the balance ability of 20 hemiplegic subjects. The authors reported significant relationships between variables related to the ability to weight shift and a subjective balance assessment (Berg Balance scale)(for path sway, $r = -0.61$, $p<0.005$), and between variables related to the ability to weight shift and measures of gait velocity (for path sway, $r = -0.67$, $p<0.002$). Although the low number of subjects in these studies restrict the power of the reported results, these studies support the hypothesis that measurements of weight distribution and weight shifting are correlated with each other, and that functional ability in hemiplegic subjects is related to measures of weight shifting and weight distribution.

In comparison to the number of studies reporting the movement of the COP during quiet stance, which use similar measurement systems to the measurement of weight shifting, there are relatively few studies of weight shifting. The subjective nature of the commands given to subjects in the study of weight shifting is a potential source of error. The mechanical nature of the weight shifting procedure necessitates simultaneous investigation of the effect of the size of the BOS, the height, weight, and position of the COG of the subjects. However initial experiments demonstrate that the measurement of weight shifting may be a valid assessment of standing balance, which correlates with functional ability. Further research is necessary to investigate these hypotheses.

3.2.8 Measurement of weight distribution in stance

Following the work by Murray and Peterson (1973), which first reported a measurement of weight distribution in stance, a number of studies have been carried out which use a variety of different measurement tools to obtain outcomes pertaining to weight distribution between the legs during quiet stance. Table 3.13 lists the measurement tools and outcome measures in some of the key studies of weight distribution and standing balance.

Murray and Peterson (1973) used a measurement system comprising of a platform in which 2 strain gauges, from commercially available bathroom scales, were mounted. The results could be continuously measured using a polygraph. The weight distribution of 40 healthy male subjects (20-60 years) was measured, during 4 one-minute test periods. Murray and Peterson (1973) reported the difference in weight distribution between the legs in kilograms. The use of kilograms as the unit of outcome limits the usefulness of these results due to the differences in body weight between the subjects. The study by Bohannon and Waldron (1991) which used 2 digital scales to measure distribution of weight in stance of 20 hemiplegic subjects

(63.2±10.1years) was also limited by the use of weight bearing in kilograms as the outcome measure.

STUDY	SAMPLE	MEASUREMENT TOOL	OUTCOME MEASURE
Bohannon and Larkin (1985)	25 hemiplegic subjects (14-87years)	2 digital scales	percentage weight bearing
Bohannon and Tinti-Wald (1991)	14 healthy subjects (48-84years); 14 hemiplegic subjects (30-84years)	2 digital scales	percentage weight bearing
Bohannon and Waldron (1991)	20 hemiplegic subjects (63.2±10.1years)	2 digital scales	distribution of body mass (kg)
Bohannon et al (1989)	61 healthy subjects (43.6±18.0years)	2 digital scales	percentage weight bearing
Caldwell et al (1986)	10 healthy females (19-25years); 10 healthy females (61-83years); 10 hemiplegic subjects (47-70years)	2 digital scales	percentage weight bearing weight on right / weight on left; or weight on unaffected side / weight on affected side
De Weerdt et al (1989)	2 hemiplegic subjects	NBP	BC = proportion of weight on left leg (left / total). SC - standard deviation of weight distribution.
Dettmann et al (1987)	15 hemiplegic subjects (46-87years)	Force platform	percentage weight bearing
Dickstein et al (1984)	11 healthy subjects (average 70years); 23 hemiplegic subjects (average 71years)	"Foot-Print" (measures foot ground pressure)	weight on left / weight on right
Gruendel (1992)	29 hemiplegic subjects (26-88years)	2 mechanical scales	average weight bearing = (max WB + min WB) / 2, expressed as percentage of total body weight.
Hocherman et al (1984)	24 hemiplegic subs	"Foot-Print" (measures foot ground pressure)	weight on right / weight on left
Murray and Peterson (1973)	40 healthy males (20-60years)	2 force transducers from bathroom scales, mounted on to platform surface	mean difference in distribution of mass between legs (kg)
Sackley (1990)	90 hemiplegic subjects (21-88 years)	NBP	BC = proportion of weight on left leg (left / total). SC - standard deviation of weight distribution.
Sackley (1991)	92 hemiplegic subjects (21-87 years)	NBP	BC = proportion of weight on left leg (left / total). SC - standard deviation of weight distribution.
Sackley and Lincoln (1991)	403 healthy subjects (18-87years)	NBP	BC = proportion of weight on left leg (left / total). SC - standard deviation of weight distribution.
Wu et al (1996)	3 hemiplegic subjects	"Balance Master"	percentage weight bearing

Table 3.13: Measurement systems and outcome measures used in studies measuring weight distribution during stance.

The use of 2 digital scales to record the distribution of weight between the legs has become a popular methodology, supported by the ease of use, the portability and the lack of expense of such a measurement tool. The percentage of weight distributed on either leg has become a frequently reported outcome measure. This has the advantage of allowing comparison between subjects of different body weight, and between different studies. However the use of digital bathroom scales also has a number of disadvantages. Unlike the initial study by Murray and Peterson (1973) in which the force transducers from the scales were removed and mounted within a specially designed platform, other studies have used the bathroom scales in their commercial form, asking subjects to place one foot on either scale (Bohannon and Larkin, 1985; Caldwell et al, 1986; Bohannon et al, 1989; Bohannon and Tinti-Wald, 1991). This places restrictions on the foot placement of the subjects and, although none of these studies identified the distance between the feet during measurement, this could potentially result in the use of a wider base of support than might be used in normal conditions. Another problem relating to the use of commercially available bathroom scales is the accuracy and precision with which they are calibrated. Many of the authors using this measurement tool stated that the scales used were calibrated prior to use, but the method for carrying out such a procedure was not explicit (Caldwell et al, 1986; Bohannon et al, 1989; Bohannon and Tinti-Wald, 1991) or the validity of the method of calibration was doubtful (Bohannon and Larkin, 1985). Bohannon and Waldron (1991) identified that the use of bathroom scales in previous studies had not been accompanied by the verification of accuracy and reliability of measurements using scales. Bohannon and Waldron (1991) attempted to address these issues, using a study of the weight distribution of 20 hemiplegic subjects. The problem with the methodology adopted by Bohannon and Waldron (1991) is that repeated measurements on subjects were used to address the accuracy and reliability of the measurement tool. This is not a measure of the reliability of the tool, but is a measure of the intra-subject reliability. It is necessary to use dead weights to identify the accuracy and the reliability of such a measurement system.

A further limitation of the use of unadapted bathroom scales is that they are only designed for instantaneous readings, and have to be taken by the tester through observation of the digital dial. Caldwell et al (1986) reported results in which the weight distribution on the two legs did not add up to 100%, due to the fact that the readings from the scales under the left and right feet were not taken at the same instant and, as a result of postural sway, the weight distribution was not the same during any two readings. Gruendel (1992) used a methodology for which the reliability and validity must be disputed. Subjects stood with one leg on each of 2 mechanical scales, for which no calibration procedure was discussed. The tester observed one of the mechanical dials over a period of one minute, and recorded the maximum and minimum values over this time. The "average weight bearing" was defined and calculated as the (maximum weight bearing + minimum weight bearing) / 2. This is not a statistically valid definition, and the conclusions of this study are consequently erroneous.

A number of studies have attempted to avoid the limitations associated with the used of digital scales, and have adopted the use of more sophisticated systems with two vertical force plates which do not restrict foot placement, and which are able to record continuous data. Dettmann et al (1987) used a specially designed force plate system to determine the percentage weight bearing through the legs of 15 male hemiplegic subjects. A computer system was used to sample, at 20Hz, the force distribution between the two legs during 30s stance. The force through the affected leg was found to be 36.1±14.6% of body weight. The force through the affected leg was found to correlate positively with parameters of walking performance: stride length (r=0.56), affected side step length (r=0.56), and swing ratio (r=0.67). This study demonstrated the potential for using measures of weight distribution as a determinant of outcome in subjects with hemiplegia; although larger scale studies would be necessary to confirm the findings by Dettmann et al (1987).

Wu et al (1996) used the "Balance Master", which is a commercially available clinical system designed for the training and assessment of standing balance. Wu et al (1996) carried out an intervention study, using an ABAB design, to assess a series of balance exercises on 3 hemiplegic subjects. The low number of subjects, and the use of the Balance Master for both the training and the assessment of the subjects limits the results of this study. De Weerdt et al (1989), Sackley (1990, 1991) and Sackley and Lincoln (1991) all used another specially designed clinically orientated system, called the Nottingham Balance Platform (NBP). The outcome measure in all of these studies consisted of 2 variables that were computed by the measurement system. The "Balance Coefficient" (BC) was defined as the proportion of weight on the left leg (weight on left / total weight). The "Sway Coefficient" (SC) was defined as the standard deviation of the weight distribution. Although the BC can be observed to be a valid representation of weight distribution between the legs (with 0 representing all the weight on the right, 0.5 representing equal weight distribution, and 1 representing all the weight on the left), the validity of using the SC, which is derived from the variations in measurements of vertical force, must be challenged. The SC provides a measure of variations in vertical force, but this cannot be assumed to correlate with the movement of the COP which occurs with postural sway. The term "sway coefficient" may therefore be misleading.

Hocherman et al (1984) and Dickstein et al (1984) both used the "Foot Print" system, which measures the pressure under the feet, in order to determine the weight distribution between feet. Hocherman et al (1984) used this system as a measure of outcome in a study of platform training with subjects with hemiplegia (n=24). Dickstein et al (1984) reported the weight bearing characteristics of 23 subjects with hemiplegia, which were determined using the Foot Print system. Although not stated, the results reported in these two studies suggest that the same sample and data were used for both studies. The Foot Print system takes an instantaneous reading of pressure, and produces a picture of the pressure distribution under the feet. Dickstein et al (1984) stated that the picture was photographed and then processed with a microcomputer to derive the weight distribution between the feet. Hocherman et al (1984) failed to discuss issues relating to the derivation of weight distribution from the picture of pressure distribution. Dickstein et al (1984) used the equation (weight on left / weight on right)(L/R), and Hocherman et al (1984) used the opposite (weight on right / weight on left)(R/L), an outcome measure. Durward and Rowe (1991) identified problems with a number of the formulae used in the literature to derive indices of symmetry of weight distribution. The use of L/R and R/L does not produce a linear response. This formula results in an index ranging from 0 to infinity, with 0.5 as the "mid" point (Durward and Rowe, 1991). Durward and Rowe (1991) stressed the importance of selecting an index of symmetry that is appropriate to the measurement.

As in the case of using digital scales, the majority of researchers have used the more sophisticated measurement systems, such as the NBP and the Foot Print, without addressing issues relating to calibration. De Weerdt et al (1989), Sackley (1990,

1991) and Sackley and Lincoln (1991) all failed to discuss the accuracy and precision of the NBP; Hocherman et al (1984) and Dickstein et al (1984) did not address either the calibration of the Foot Print system, or the reliability of the method of determining the weight distribution from the pressure output. This limits the value of the results from any of these studies. It is vital that any future studies using measurements of weight distribution first thoroughly investigate the accuracy, precision and reliability of the proposed measurement tool. Similarly to the measurements of postural sway, the value of the results of the measurement of weight distribution are further compromised by the use of different positions of stance, or by the failure to state the standing position.

Despite the differences in the methodologies of the studies of weight distribution during stance, the results from different studies often support similar hypotheses. Sackley and Lincoln (1991) used the NBP to record normative values from a large sample (n = 403) of healthy subjects (18-87 years). The mean BC for the group was 0.517(±0.051), with 95% confidence intervals of (0.417, 0.617). The largest difference in weight distribution between the legs was 12% for 95% of the sample, with the remaining 5% ranging between 13% and 22%. Caldwell et al (1986) recorded weight distribution of between 44.2% and 55.7% on either leg for 10 healthy females aged 19-25 years, and a weight distribution of between 42.1% and 57.0% on either leg for 10 healthy females aged 61-83 years. The data recorded by Caldwell et al (1986) indicated a slightly smaller difference in weight distribution between the legs than found by Sackley and Lincoln (1991). However, the differences were small and Sackley and Lincoln (1991) concluded that both studies supported the hypothesis that healthy subjects have up to 12% difference in weight distribution between the legs during stance. Although Caldwell et al (1986) reported that the maximum range for the elderly group was slightly greater than that of the younger group, the authors concluded that age did not affect the difference in weight bearing between the legs. In contrast, Sackley and Lincoln (1991) determined correlation coefficients for the association between age and the symmetry of weight distribution in stance, reporting that there was a significant association ($r = 0.17$, $p<0.001$). However the correlation coefficient reported ($r=0.17$) indicates that the association between age and weight distribution was very low. Although studies using different outcome variables cannot be directly compared with these results, they do demonstrate that groups of healthy subjects have a mean weight distribution that is approximately symmetrical, and a difference in weight distribution between the legs of approximately 12%. Dickstein et al (1984) calculated weight on left / weight on right for 11 healthy subjects (mean age 70 years), and concluded that the mean value was 1.09 with a range from 0.83 - 1.35. Rather than requesting subjects to stand upright, to look straight forwards, or using a similar non-specific command, as in the case of most studies of standing balance, Bohannon and Tinti-Wald (1991) asked subjects to attempt to take a specific amount of weight through one leg. When attempting a target of 50% of weight on each leg, the mean value for a sample of 14 healthy subjects (48-84 years) was 48.9%±4.3%, with a range from 38.1%-58.6%. These results appear to be similar to the results from studies using non-specific commands, suggesting that these results may not be related to the commands given.

A number of studies have taken measurements of weight distribution from samples of subjects with hemiplegia. Differences in the subjects, for example time since onset of stroke, severity of stroke, and treatment received, make comparison between studies difficult. However the studies are all in agreement in concluding that subjects with hemiplegia, on average, apply more weight to their unaffected side than to their affected side (Dickstein et al, 1984; Bohannon and Larkin, 1985; Caldwell et al, 1986; De Weerdt et al, 1989; Sackley, 1990, 1991; Wu et al, 1996). Sackley (1990) demonstrated correlations between symmetry of weight distribution in stance and motor function and activities of ADL; Sackley (1991) found a relationship between symmetry of weight distribution and length of hospital admission. Sackley (1990) found no relationship between weight distribution and the number of falls in hemiplegic patients.

3.2.9 Summary and conclusions

Many studies have attempted to measure aspects of standing balance. All of the identified methods of measurement of balance have been adopted in the assessment of standing balance. Problems with reliability, validity and sensitivity were found in studies using observation and scored tests. Timed tests of standing balance were limited in their usefulness, due to the lack of reliability, validity and distinctiveness of these tests. The measurement of muscle activity using EMG provided interesting results pertaining to variations in activity in specific muscles in response to a perturbation. However the use of EMG in the assessment of more global problems of standing balance may not be appropriate as balance responses were found to be specific to the methods of perturbation and the results from single muscles cannot validly be generalised to provide an assessment of standing balance. Difficulties with the measurement procedures and with data analysis for EMG measurements and for the measurement of body parts restrict the ability of these methods of measurement to provide data that is accurate, precise and reliable.

Measurements of the COP during quiet stance and during weight shifting in stance have been popular. These studies have demonstrated that, during quiet stance, the variation in repeated measures from an individual is similar to the variation among a group of individuals. COP measurements during both quiet stance and weight shifting activities have been taken from healthy subjects and subjects with hemiplegia. These studies have demonstrated that there are differences between the COP measures for healthy and hemiplegic subjects. However, comparison between the different studies is confounded by the failure to standardise the testing protocols and by the use of a variety of different parameters related to the COP. No studies have identified relationships between measures of the COP during quiet stance and measures of functional ability. It has been suggested that traditional outcome variables derived from the measurement of the COP are not valid reflectors of postural stability. The validity of using measures of the COP during quiet stance for the assessment of standing balance must, therefore, be challenged. Although there have been fewer studies of the COP during weight shifting than there have been during quiet stance, initial experiments have suggested that the measurement of the COP during weight shifting may correlate with functional ability. This indicates that the measurement of the COP during weight shifting might be a valid and appropriate method of assessing standing balance. Further research is required to investigate this hypothesis.

A number of studies have taken measurements of weight distribution between the legs during stance. This has been a popular method of measurement with subjects with hemiplegia. Several studies have found that there were relationships between the symmetry of weight distribution in standing and measures of functional ability, in patients with hemiplegia. These studies indicate that weight distribution may be an appropriate measurement of ability to stand. Despite it's apparent appropriateness, the validity of weight distribution as a measure of standing balance has not been addressed. Many of the studies reviewed used measurement systems which had not been calibrated, or for which the calibration had not been assessed. Any future studies using measurements of weight distribution in standing should include extensive checks of the calibration of the measurement system. The validity of some results is questionable due to the index of symmetry used as an outcome measure. Future studies should use indices of symmetry that can be demonstrated to be appropriate to the measurement.

3.3 *Balance and reaching*

3.3.1 Introduction

Reaching is a universal activity, essential to daily living. Reaching is principally a movement of the upper limb, and many studies have investigated the control of reaching with reference to two phases - 1) the transport phase and 2) the grasp phase (van Vliet, in press). Variables which have been reported in the investigation of reaching primarily include measurements of the movement time and velocity and EMG recordings from major muscle groups (e.g. Moore and Brunt, 1991; Moore et al, 1992; Jeannerod, 1994; van Vliet, 1995a; Dean and Shepherd, 1997). These measurements have led to the identification of anticipatory muscle, or postural, adjustments (Frank and Earl, 1990; Moore and Brunt, 1991; Moore et al, 1992), which occur prior to the movement of the reaching limb.

Many studies of reaching have investigated the execution of rapid reaching tasks, where subjects have been requested to reach to a target as fast as possible (e.g. Moore and Brunt, 1991; Moore et al, 1992; Trombly, 1993; Crosbie et al, 1995; Dean and Shepherd, 1997). However a number of studies have also explored reaching to the limits of stability, as an assessor of balance in sitting and standing (Duncan et al, 1990b). Neurological damage frequently results in a loss of control of the upper limb; many studies with neurologically damaged populations have explored reaching with respect to the affected upper limb; however a few studies have identified the importance of trunk activity for balance during reaching and have investigated reaching with the unaffected arm.

The following sections will review

a) Studies of reaching and anticipatory postural adjustments;
b) Studies of reaching and sitting balance;
c) Studies of reaching and standing balance;
d) Studies of the reaching ability of hemiplegic subjects.

3.3.2 Studies of reaching and anticipatory postural adjustments

Many studies of anticipatory postural adjustments have used arm movements other than those associated with reaching to measure the responses of different muscle groups. These studies support the hypothesis that anticipatory adjustments occur to ensure that the subject remains in a balanced position during the application of dynamic forces (Friedli et al, 1984, 1988; Horak et al, 1984; Bouisset and Zattara, 1987; Vernazza et al, 1997). Friedli et al (1988) measured the movement of the COP before and during rapid elbow movement in stance and concluded that the postural muscles acted to maintain the COP within 8cm of the resting position of the COP during the movement; this was a smaller movement than would have occurred without the postural adjustments (Friedli et al, 1988). Vernazza et al (1997) compared the actual displacement of the COG (found using a motion analysis system) with the theoretical displacement of the COG (based on biomechanical modelling) during arm raising by healthy subjects. The authors found that the actual displacement of the COG was less than the theoretical displacement. This led to the hypothesis that during arm raising there were postural adjustments that acted to minimise the displacement of the COG (Vernazza et al, 1997).

Studies of anticipatory postural adjustments during reaching from sitting have demonstrated that trunk movement occurs in the direction opposite to the arm acceleration (Moore and Brunt, 1991; Moore et al, 1992). These results question whether the postural adjustments are related to the maintenance of balance during the destabilising movement of the arm, or whether they are directly related to the reaching movement. Mechanical laws dictate that, in response to the initial shoulder to arm force causing acceleration of the arm, there will be an equal and opposite arm to shoulder force. This equal and opposite force may cause trunk acceleration in the opposite direction, or may be transmitted to the support surface, or a combination of both of these. Moore and Brunt (1991) observed trunk movement in the opposite direction to the arm acceleration; it could, therefore, be hypothesised that this was the result of the equal and opposite force on the trunk, resulting in trunk movement in the opposite direction to the arm acceleration. However, the outward movement of the arm will alter the position of the subject's COM. An alternative explanation for the movement of the trunk in the opposite direction to the arm could consequently be that trunk movement occurred in an attempt to maintain the position of the COM within the BOS. The control of the COM with respect to the BOS is central to the maintenance of balance. While trunk movement as a direct result of the mechanical effects of the arm acceleration would occur at the same time as the arm movement; control of the COM could theoretically occur as an anticipatory balance reaction. Moore and Brunt (1991) did not discuss the timing of the trunk movement relative to the initiation of arm movement. Moore et al (1992) did not identify clear evidence of anticipatory postural responses, and were thus unable to support the hypothesis that anticipatory movements occurred during reaching from a seated position.

Thus although there is evidence which has clearly identified the existence of anticipatory postural responses in order to maintain balance during dynamic arm movements in stance, the evidence supporting a similar response in sitting is not clear. However it can be demonstrated using the laws of mechanics that the motion of reaching out, from a sitting or a standing position, will result in a reaction force on the body, acting to move the COP in the opposite direction from the direction of arm movement. Reaching from sitting or standing therefore results in a challenge to balance. It is imperative that the COP remains within the BOS in order to maintain balance. In stance it has been demonstrated that muscle activation occurs prior to a reaching movement in order to control the position of the COP; the position of the COP is also controlled during reaching in sitting although it is not clear whether this is an anticipatory response or not.

3.3.3 Studies of reaching and sitting balance

There are few studies that have investigated the effect of reaching out from a sitting position on balance. Studies that have been carried out have primarily investigated the influence of the lower limbs on sitting balance (e.g. Chari and Kirby, 1986; Crosbie et al, 1995; Dean and Shepherd, 1997). These studies demonstrated that the lower limbs do contribute to the ability of a subject to maintain balance during reaching forwards.

Chari and Kirby (1986) recorded data while healthy subjects reached to a maximum distance at angles of 0, 15, 30 and 45° to either side, using the hand on that side. The study results demonstrated that the distance of reach increased with angles from 0° to 45° ($p<0.001$) (Chari and Kirby, 1986). Crosbie et al (1995) asked healthy subjects to reach to specific distances to the front and at 45° to either side. The reasons for the selection of the specific distances were not explained, and opposed the earlier findings of Chari and Kirby (1986). It could be argued that the use of maximum reach is a more appropriate measurement of sitting balance than reaching to a specified distance, which may place restrictions on the subject. Although both of these studies had low numbers of subjects and used different testing protocol, which limits the ability to generalise the results, these studies highlight the potential for measurements of reaching in the investigation of sitting balance.

Dean and Shepherd (1997) carried out an intervention study to investigate the effect of hemiplegic patients carrying out a training program specifically aimed at obtaining the appropriate loading of the affected leg during reaching. 10 hemiplegic subjects (experimental group) carried out the training program, which "involved emphasis on appropriate loading of the affected leg while practising reaching tasks using the unaffected hand to grasp objects located beyond arm's length." 10 hemiplegic subjects (control group) carried out a training program involving cognitive manipulative tasks performed sitting at a table, using less than 50% of arm length as the maximum reach. Both training programs comprised of 10 sessions over 2 weeks. The maximum reaching distance, the duration of the reach, and the vertical GRF all improved in the experimental group, but not in the control group. The experimental group was also found to demonstrate an increase in the peak GRF through the affected limb during rising to stand: this finding suggests that ability to reach may be related to functional ability in other tasks. However, this study is limited by the apparent failure to keep the tester or the trainer blind to the study aims or results. It appears that the same person carried out the training programs and the testing. The training program involved systematic changes to the distance and direction of reach; the changes were controlled by the same person. This person gave verbal encouragement to the subjects; this encouragement was not controlled in any way. In addition one of the outcome measures was the time taken to perform the reaching task. Previous experiments (e.g. Horak et al, 1984) have hypothesised that more rapid movements are less precise than slower movements. The validity of duration of reach as an indicator of an improvement must therefore be challenged. Thus, while this is the first reported study of reaching from sitting with subjects with hemiplegia, the methodology limits the value of the results. Further, well-controlled studies of reaching in subjects with hemiplegia are required.

3.3.4 Studies of reaching and standing balance

Although a number of studies have investigated the ability to maintain balance during rapid arm movements in stance, little research has investigated the effects of reaching the arm out at slower speeds (Wing et al, 1992). Wing et al (1992) investigated the effect of raising an arm up to 90° of abduction on the position of the COM. 203 healthy subjects (16-79 years) stood in a standardised position on a pair of electronic weighing scales. Subjects raised their left arm, and a reading was taken from the scales; and then subjects repeated this with their right arm. All subjects were demonstrated the measurement system immediately prior to testing, and were shown their results immediately after each test. There was a significant difference between the weight shifting when lifting the left and the right arm ($p<0.01$); the authors suggested that this difference may be due to the knowledge of results after raising the left arm. Theoretical biomechanical analysis of the movement, based on average body weight and anthropometric measures, is a powerful tool for identifying the effects of compensatory balance reactions. The authors carried out biomechanical analysis and concluded that without compensatory action, the percentage change in weight distribution would be 6.2%. This experiment therefore demonstrated that compensatory reactions did occur. However the knowledge of the subjects pertaining to the study means that one cannot validly conclude whether the compensatory reactions were pre-programmed balance reactions, or cognitively-planned voluntary movements.

Duncan et al (1990b) designed the "Functional Reach" test (FR) to assess standing balance. The authors defined FR as "the maximum distance one can reach forward beyond arm's length, while maintaining a fixed BOS in the standing position". 128 healthy subjects were tested in this study. Two different tests were carried out; one in which COP movement was measured using a force plate and distance of FR was measured using an electronic measurement system, and one in which FR was measured using a metre stick. Subjects carried out 3 trials of each test. Statistical tests were carried out in order to investigate correlation between the COP measures, the electronic FR and the metre-stick FR. The authors concluded that the distance of functional reach correlates strongly with COP excursion measures (Pearson's correlation coefficient − 0.71). The correlation between the electronic and the metre stick measurements of FR was 0.69. The authors concluded that this test of functional reach was "a new dynamic measure of postural control that is inexpensive, precise, stable, age-sensitive, and clinically accessible". It was identified that the FR was not a direct measure of COP excursion, although the two variables were conceptually related. This study has highlighted the potential for using measurements of reaching as valid and reliable tests of ability to balance. This test measured reaching forwards with the arm at 90°; further research is necessary to investigate the correlation between COP excursion and reaching to different angles.

Fishman et al (1996) compared the Functional Reach test with measures of postural sway and symmetry of weight distribution during platform perturbation tests, in 20 subjects with hemiplegia. The authors concluded that FR and symmetry of weight distribution in stance during platform perturbation appeared to be related ($p<0.001$), while FR and postural sway during platform perturbation were not related. A lack of provision of information pertaining to this study limits the ability to draw firm conclusions; however, these results highlight that different outcome measures are not necessarily related and may measure different aspects of balance.

3.3.5 Studies of the reaching ability of hemiplegic subjects

A small number of studies have investigated the reaching ability of hemiplegic subjects without specific discussion of the relationship between reaching and balance. Some of these studies have addressed issues specifically related to problems with the affected arm (e.g. Wing et al, 1990); while other studies have investigated the ability to reach with either the affected or unaffected arm (eg. Trombly, 1993; van Vliet et al, 1995a). Studies specific to the affected arm are investigating the control of the hemiplegic limb and are not therefore directly related to the study of balance.

Trombly (1993) carried out a study with the aim of identifying reaching improvement in hemiplegic patients over a period of time. However the methods of measurement (EMG and 3-D analysis of finger movement) and the derived outcome measures assessed the control over the reaching arm (both affected and unaffected limbs were tested) but did not allow the assessment of aspects related to balance. Van Vliet et al (1995a and 1995b) used a 2-D video analysis technique to derive variables of movement time, average velocity, peak velocity, and time at which peak velocity occurred (as percentage of movement time) in studies of the reaching ability of healthy and hemiplegic subjects. Although it could be argued that measures of time and velocity may provide information pertaining to the control of the movement, and hence the control of balance during reaching from sitting, this study does not address issues relating to balance.

As has been identified, trunk movement is integral to reaching from sitting (Moore and Brunt, 1991; Moore et al, 1992). Although not aimed at addressing issues relating to balance and reaching, a number of studies have assessed trunk muscle strength during sitting, in patients with hemiplegia. Bohannon et al (1995) measured the trunk flexion strength, in lateral and forward planes, of 20 hemiplegic patients and 20 control subjects. The authors concluded that patients with stroke exhibited impaired trunk muscle strength multidirectionally. Lateral flexion to the affected side was generally weaker than lateral flexion to the unaffected side, in patients with stroke, although this pattern was reversed in a number of subjects (Bohannon et al, 1995). Tanaka et al (1997) measured isokinetic trunk rotation strength in 65 patients with hemiplegia and 80 control subjects. As in the study by Bohannon et al (1995), the results showed that patients with stroke had lower motor performance than healthy subjects in both directions. However, in contrast to Bohannon et al (1995) who reported greater weakness during flexion to the affected side, Tanaka et al (1997) found no significant difference between rotation to the affected or unaffected side. Although these studies have not directly addressed balance and reaching, the multidirectional loss of trunk motor performance suggests that balance during reaching may also be impaired multidirectionally.

Thus, while studies of reaching with hemiplegic subjects could potentially provide valuable information pertaining to balance, no studies were found that directly addressed balance and reaching in hemiplegic subjects.

3.3.6 Summary and conclusions

Although there is a substantial amount of literature pertaining to reaching few studies address issues relating to balance. Studies of anticipatory postural adjustments have demonstrated that these occur prior to reaching movements in standing. Although postural adjustments have been observed to occur in response to reaching from a sitting position, the research is inconclusive as to whether the response occurs in anticipation of the reach. Studies of balance during reaching from a sitting position have largely concentrated on the influence of the lower limbs during reaching. Studies of balance during reaching from a standing position have primarily used other measures of balance (e.g. movement of the COP, Duncan et al, 1990b; weight distribution, Wing et al, 1992) in the investigation of reach. The study by Duncan et al (1990b) highlights that measures of functional reach in stance may be valid and reliable assessors of standing balance. Studies of reaching ability in hemiplegic subjects have tended to concentrate on temporal or displacement variables, without discussing the implications of balance on the reaching movement.

Although there is little literature available relating to balance during reaching, studies have demonstrated that reaching from sitting necessitates postural responses in the trunk and lower limbs. It can be argued that reaching from sitting is a method of producing a standardised methodology for weight-shifting during sitting. Thus it is hypothesised that tests of reaching result in assessments of weight-shifting, and that reaching may provide a valid method of assessing balance. Reviews of studies using measures of the COP during weight-shifting in sitting and standing have led to the conclusion that the validity of using variables related to the COP as the measure of outcome was unknown. However, methods of measurement other than the assessment of the COP may be appropriate. It is proposed that measurements of weight distribution during reaching out from sitting in the lateral direction may be suitable for the assessment of balance.

3.4 Balance and rising to stand and sitting down

3.4.1 Objective assessment of rising to stand and sitting down

The analysis of the functional activities of rising to stand and sitting down have had relatively little research (Kerr et al, 1997), unlike the extensive investigations which have been carried out into both healthy and pathological gait. Objective assessment of aspects of rising to stand and sitting down did not become prevalent until the 1970's (Pai and Lee, 1994; Kerr et al, 1997). The research which has been carried out since the 1970's has primarily concentrated on the analysis of the activity of rising to stand, and the data pertaining to sitting down remains scarce (Kerr et al, 1997). Studies which have explored the activity of sitting down include Yoshida et al (1983), Kralj et al (1990), Engardt and Olsson (1991a,b, 1992), Engardt et al (1993), Durward (1994), Kerr et al (1994a,b, 1997) and Mourey et al (1998).

Kerr et al (1991, 1994b) have identified that the research which has been carried out into rising to stand and sitting down can be broadly classified into 4 main areas:-

1. Biomechanical investigations (kinetic studies), based on the analysis of force plate data;
2. Kinematic studies, based on the measurement of joint angles;
3. Investigations into muscle activity, based on EMG analysis;
4. General studies of the functional aspects of sitting.

Studies using kinetic data have primarily collected force data by means of one or two force plates positioned under the feet of the subject. Kinetic data pertaining to the forces applied through the arms during rising to stand has also been measured using force measuring sections under the hands (Alexander et al, 1989; Durward, 1994). Although some studies have placed additional force plates in the seat of the chair or under the legs of the chair (Pai and Rogers, 1990, 1991a,b; Pai and Lee, 1994; Pai et al, 1994a; Hanke et al, 1995), this data appears to have solely been used for the identification of the point where the subject leaves the seat ("seat-off"), and no studies have carried out further analysis of this data.

Measurement of joint angles has been collected using a number of different tools: these have included photography (Ellis et al, 1984; Stevens et al, 1989; Kralj et al, 1990), cinematography (Kelley et al, 1976; Munton et al, 1984; Nuzik et al, 1986; Fleckenstein et al, 1988; Roebroeck et al, 1994) and videographing (Alexander et al, 1989; Shepherd, 1991; Carr, 1992; Millington et al, 1992; Hughes et al, 1994; Hughes and Schenkman, 1996; Magnan et al, 1996; Crosbie et al, 1997). These tools have been used in combination with simple markers or LED's placed on known anatomical points. Systems which can translate the motion recorded on video into computerised digits have been adopted in more recent studies (e.g. Ada and Westwood, 1992; Carr, 1992; Millington et al, 1992; Magnan et al, 1996). More recently the use of 3-D computerised motion analysis systems have enhanced the investigation of rising to stand: the two most frequently used systems being the Selspot/TRACK system (e.g. Berger et al, 1989a,b; Rodosky et al, 1989; Riley et al, 1990, 1991; Schenkman et al, 1990; Ikeda et al, 1991) and the WATSMART motion analysis system (e.g. Pai and Rogers, 1990, 1991a,b; Pai and Lee, 1994; Pai et al, 1994a; Hanke et al, 1995). Information from the kinematic measurement tools has allowed the development of segmental models and mathematical formulae from which it is possible to derive information such as the velocity and momentum of the body and body parts, and the moments around specified joints. From this information further derivation can provide data pertaining to the kinetic aspects of the movement.

Studies	Kinetic data	Kinematic data	EMG
Ada and Westwood (1992)		videography	
Alexander et al (1989)		videography	
Baer and Ashburn (1995)		motion analysis system	
Berger et al (1989a,b)		motion analysis system	
Carr (1992)	x	videography	
Crosbie et al (1997)	x	videography	
Durward (1994)	x		
Engardt and Olsson (1991a,b,1992)	x		
Engardt et al (1993)	x		
Fleckenstein et al (1988)		cinematography	
Hanke et al (1995)	x	motion analysis system	
Hughes and Schenkman, (1996)	x	videography	
Hughes et al, (1994)		videography	
Ikeda et al, (1991)		motion analysis system	
Kelley et al (1976)		cinematography	x
Kerr et al, (1994b, 1997)		motion analysis system	
Kotake et al (1993)		motion analysis system	
Kralj et al (1990)	x	photography	
Lee et al (1997)	x	inclinometer for knee joint angular displacement	x
Magnan et al, (1996)	x	videography	
Millington et al (1992)	x	videography	x
Mourey et al (1998)		motion analysis system	
Munton et al (1984)		cinematography	
Nuzik et al, (1986)		cinematography	
Pai and Lee (1994)	x	motion analysis system	
Pai and Rogers (1990, 1991a,b)	x	motion analysis system	
Pai et al, (1994)	x	motion analysis system	
Riley et al, (1990)	x	motion analysis system	
Rodosky et al (1989)	x	motion analysis system	
Roebroeck et al, (1994)	x	cinematography	
Schenkman et al, (1990)	x	motion analysis system	
Shepherd (1991)		videography	
Shepherd and Koh (1996)	x	videography	
Shepherd et al (1997)	x	videography	
Stevens et al (1989)	x	photography	x
Vander Linden et al (1994)	x	motion analysis system	x
Wheeler et al (1985)		videography electrogoniometry	x
Wretenberg et al (1993)	x	videography	
Yoshida et al (1983)	x	x	

Table 3.14: Methods of measurement adopted by studies of rising to stand. (x = method used).

Table 3.14 lists some of the studies of rising to stand and the method of measurement. This table demonstrates that, while Kerr et al (1991, 1994b) are correct in the observation that studies may collect kinetic or kinematic data, the majority of studies carried out have used a combination of techniques.

A number of studies have attempted to use objective assessments to identify parameters relating to aspects of balance during rising to stand and sitting down. These include investigations of the displacement of the centre of mass (COM) in relation to the base of support (BOS) (e.g. Pai and Rogers, 1990, 1991; Schultz et al, 1992; Hughes et al, 1994; Pai and Lee, 1994; Pai et al, 1994; Hughes and Schenkman, 1996; Magnan et al, 1996); and of the symmetry of weight distribution during rising to stand (Engardt and Olsson, 1991a,b, 1992; Engardt et al, 1993; Durward, 1994; Baer and Ashburn, 1995). Studies of rising to stand and sitting down have used a variety of methods in order to classify the movement cycle into phases. In order to review the studies relating to aspects of balance and rising to stand / sitting down it is imperative that the different methods of demarcating the movement into phases are first identified. The following sections review the literature pertinent to the division of rising to stand and sitting down into a variety of different phases, and the literature exploring aspects of balance during rising to stand and sitting down.

3.4.2 Phases of rising to stand and sitting down

There is no one accepted method of classifying rising to stand and sitting down into phases. One of the most frequently used methodologies involves the movement of the COM. Kelley et al (1976) first illustrated, using analysis of displacement of body parts, that the movement of the COM comprised an initial horizontal displacement and subsequent vertical displacement. This finding was later confirmed by a number of studies, which used both kinetic and kinematic variables, rather than just angular data, to derive further data pertaining to the displacement and velocity of the COM (Pai and Rogers, 1990; Riley et al, 1990; Schenkman et al, 1990; Roebroeck et al, 1994; Hanke et al, 1995).

Pai and Rogers (1990) and Hanke et al (1995) divided the movement of rising to stand into distinguishable temporal phases by identifying the initial and final movement of the COM in the horizontal direction, and the time of the peak velocity of the COM in the horizontal and vertical directions. Rather than using the velocity of the COM, Schenkman et al (1990), Riley et al (1991) and Roebroeck et al (1994) divided the movement into phases based on the change in the momentum of the COM from the horizontal to the vertical. The "momentum-transfer" phase was defined as the phase in which the horizontal (flexion) momentum was transferred into vertical (extension) momentum (Schenkman et al, 1990).

Despite the use of components related to the velocity and momentum of the COM the individual phases and method for determining the start and finish of each phase varied between the identified studies. It is generally accepted that the movement of rising to stand involves a horizontal and a vertical component, with a transition from the forward lean to the extending phase (Pai and Rogers, 1990; Schenkman et al, 1990; Riley et al, 1991; Kerr et al, 1994b). However, the kinetic and kinematic events used to divide the movement into the forward lean and extending phases remain to be established. This lack of consensus in the terminology make comparison between different studies complicated (Baer and Ashburn, 1995). Although complex methodologies have been used to divide the movement into phases, some studies have dealt with the entire movement sequence without defining phases. Mourey et al (1998) and Engardt and Olsson (1991a,b, 1992) investigated both rising to stand and sitting down as one movement sequence.

Although many studies have used complex methods of determining phases of movement during rising to stand and sitting down; the studies which have only recorded kinetic data lack the ability to determine such complicated phases. Engardt and Olsson (1991a,b, 1992) compared the kinetic data from standing up and sitting down, and did not attempt to further divide the movement into smaller phases. However, Durward (1994) recorded kinetic data, using four force plates under the feet and strain gauges measuring the forces through the arm rests, during rising to stand and sitting down and concluded that the duration of time taken to complete the initial forward flexion during rising to stand, and the final extension at the end of sitting down appeared to be irregular characteristics of the movement cycle. Durward (1994) suggested that the analysis of data pertaining to rising to stand and sitting down, which included data from the initial forward flexion and final extension phases, could potentially introduce excessive variability into the results. Durward (1994) proposed that rising to stand and sitting down should each be defined as comprising two distinct phases – an initial flexion phase followed by the ascending phase, and a descending phase followed by a final extension phase. In order to avoid the introduction of the variability observed in the initial flexion and final extension phases, Durward (1994) excluded these phases from the data analysis. The measurement system used by Durward (1994) was unable to measure all the vertical forces through the chair during the periods when the body was in contact with the chair. This led to the classification of the ascending phase and descending phase as being those parts of the movement when the body was not in contact with the seat of the chair; using a switch on the seat of the chair allowed the easy identification of these phases. Durward (1994) argued that the use of complicated biomechanical data to divide the movement cycle into phases, such as used in other studies, was complicated and unnecessary. The author proposed that the use of the seat-switch was a suitable and convenient method of dividing the movement into phases. While the method of dividing the movements of rising to stand and sitting down into phases proposed by Durward (1994) could be argued to be a simple and easily administered methodology, Durward (1994) recognised that the main limitation of the utilised measurement system was the inability to measure all of the vertical forces passing through the chair. This inability prevented the assessment of factors relating to the initial flexion or final extension phases of the movement. Adapting the measurement system utilised by Durward (1994), to incorporate a method of measuring the vertical forces passing through the seat of the chair, could potentially provide a methodology for thorough exploration of kinetic data during the initial flexion, ascending, descending and final extension phases of rising to stand and sitting down.

In addition to the number of different methods of dividing rising to stand into phases, there have been variations in the definition of the start and end of the movement cycle. Table 3.15 identifies some of the methods defined to identify the start and end of rising to stand by different authors.

Study	Start of rising to stand	End of movement
Baer and Ashburn (1995)	first discernible body movement	Shoulders move back to achieve upright position
Carr (1992)	thighs off	when horizontal velocity of hip ≤0.10m/s.
Durward (1994)	seat-off	when investigator judged rising motion to be complete
Fleckenstein et al (1988)	when trunk starts to move forwards	when subject comes to rest in standing position
Gioftsos and Grieve (1996)	when total vertical force changed by > 2.5% of its' value during relaxed sitting	when total vertical force > 97.5% of its' value during relaxed standing
Hanke et al (1995)	when magnitude of horizontal momentum > 7% of peak value (Pai and Rogers, 1990)	when magnitude of horizontal momentum < 7% of peak value (Pai and Rogers, 1990)
Hughes and Schenkman (1996)	light cue command to subject	when COM reached maximum vertical position
Hughes et al (1994)	light cue command to subject	when COM reached maximum vertical position
Lee et al (1997)	first instant of forward trunk flexion	when knee angle reached "stable, constant value" for 3 seconds
Magnan et al (1996)	first shoulder movement	when COM reached maximum vertical position
Mourey et al (1998)	when angular velocity of trunk forward flexion > 10% of peak value	when angular velocity of trunk backward returning < of 10% peak value
Pai and Lee (1994)	when momentum of COM or first segment of body exceeds 2 standard deviations of mean baseline (mean of 1st 500ms of reading).	when momentum of COM decreases to less than 2 standard deviations of mean baseline (mean of last 500ms of reading).
Pai and Rogers (1990)	when magnitude of horizontal momentum > 7% of peak value	when magnitude of horizontal momentum < 7% of peak value
Pai and Rogers (1991a,b)	when magnitude of horizontal momentum > 7% of peak value	when magnitude of horizontal momentum < 7% of peak value
Pai et al (1994)	when momentum of COM or first segment of body exceeds 2 standard deviations of mean baseline (mean of 1st 500ms of reading).	when momentum of COM decreases to less than 2 standard deviations of mean baseline (mean of last 500ms of reading).

Table 3.15: Methods of identifying the start and end of rising to stand.

Many studies fail to identify why the specific start and end points were identified, or the methodology with which the points were determined. The lack of ability to accurately define the start and end of rising to stand, or sitting down, and the variation in the methods used by researchers to identify these points, combined with the use of a variety of different phases, makes comparison of different studies impossible. The differences in the methods used are highlighted by exploration of the reported time taken by subjects during rising to stand and sitting down. For example, Durward (1994) reported a mean time to rise to stand of 0.98±0.27 seconds, which was considerably less than the weighted mean of 1.8 seconds derived from reviewed studies (Durward, 1994). However, Durward (1994) acknowledged that these results reflected the decision to include only the seat-off phase of rising to stand. Durward (1994) reported that there was considerable variation in the time taken for the flexion (seat-on) phase of rising to stand, stating times of 0.89±2.6 seconds. Mourey et al (1998) reported times to rise to stand of 1.31±0.11 seconds for young subjects and 1.33±0.24 seconds for elderly subjects. Although less than the weighted mean derived by Durward (1994), the times reported by Mourey et al (1998) are comparable with those reported by Durward (1994).

Few studies have investigated sitting down; Durward (1994) reported a mean time of 2.04±0.4 seconds, and attributed the difference between this value and the 2.5 seconds reported by Engardt and Olsson (1992) to variations in the testing procedures. Mourey et al (1998) reported times to sit down of 1.40±0.15 seconds for young subjects and 1.69±0.31 seconds for elderly subjects. These times are considerably less than those reported by Durward (1994) and Engardt and Olsson (1992). Mourey et al (1998) failed to compare the time determined in their study with values available in the literature. Several studies have reported the time taken by subjects with hemiplegia to rise to stand. These times vary from mean times of 3.49±1.64s and 2.48±1.35s reported by Durward (1994) at different stages of rehabilitation, to a mean time of 1.67±0.27s (Baer and Ashburn, 1995). The times to sit down found by Durward (1994) were 3.69±1.0s and 3.50±0.79s for subjects with hemiplegia. The greater times taken by subjects with hemiplegia than by healthy subjects, and the greater time taken to sit down than rise to stand could potentially provide information relating to functional ability. However, at present comparison of the results from different studies is confounded by the lack of standardisation of the time phases recorded. Future studies of rising to stand and sitting down should attempt to define and use simple and informative phases with valid and reliable methods of identifying the start and end of each phase.

3.4.3 Balance during rising to stand

Rising to stand involves the transition from a relatively large base of support (BOS) in sitting, to a smaller base of support in standing (Hanke et al, 1995; Lee et al, 1997). It has been proposed that the necessity for this displacement of the centre of mass (COM) makes rising to stand a useful model for the study of human balance and movement control (Berger et al, 1989; Carr, 1992; Hanke et al, 1995; Mourey et al, 1998). Studies of rising to stand have identified that the movement involves a vertical and a horizontal component (Pai and Rogers, 1990; Schenkman et al, 1990; Roebroeck et al, 1994). Pai and Rogers (1990) described the initial horizontal propulsion of the body in rising to stand as a "self-generated disturbance to upright equilibrium". The control which a subject demonstrates over the horizontal movement of the COM in order to move from one BOS to another is critical to balance control (Pai and Rogers, 1990, Hughes et al, 1994). Pai et al (1994) emphasised that, unless a subject is unable to overcome the vertical pull of gravity, disturbances in balance are generally related to a horizontal displacement of the COM away from the BOS.

Many studies have been carried out which have measured the displacement of the COM in relation to the BOS or which have measured aspects of the horizontal momentum of the COM. Although few of these studies discuss the data obtained in relation to the concept of balance, these studies have produced results and conclusions that are central to balance control during rising to stand.

Lee et al (1997) reported one of the few studies that has investigated rising to stand and balance. This study aimed to explore the relationship between dynamic balance responses and motor control patterns during rising to stand in patients with stroke. EMG responses from a number of lower limb muscle groups, ground reaction forces under the feet, and knee angular displacement data was collected from 9 healthy elderly and 14 hemiplegic subjects. The EMG motor responses and 6 "COF balance indexes" (variables derived from the COF measures) were found to correlate with functional ability, assessed using the FIM (Functional Independence Measure) score. This suggests that there is a relationship between balance during rising to stand and functional ability. However the authors failed to identify the statistical tests or correlation values that demonstrated the relationship between these measures. This limits the ability to generalise from these results.

It has been identified that central to the maintenance of balance during rising to stand is the horizontal distance between the COM and the BOS at the start of the ascending phase (COM/BOS separation) (Riley et al, 1991; Carr, 1992; Schultz et al, 1992). Studies have identified that forward flexion of the trunk prior to seat off is a strategy used to decrease the magnitude of the COM/BOS separation (Wheeler et al, 1985;

Hughes et al, 1994; Hughes and Schenkman, 1996). However, in addition to the ability to move the COM through forward flexion, subjects have the ability to move the BOS nearer to the COM by moving their feet backwards (Wheeler et al, 1985).

Analysis and comparison of the horizontal and vertical components of the movement has demonstrated that the control and regulation of the horizontal displacement and momentum of the COM is central to the maintenance of balance during rising to stand (Pai and Rogers, 1991; Pai and Lee, 1994; Magnan et al, 1996).). It has been found that, while there can be increases in the peak vertical momentum of the COM, the horizontal momentum is a relatively invariant feature of rising to stand (Pai and Rogers, 1990; Pai and Lee, 1994; Pai et al, 1994; Hanke et al, 1995; Magnan et al, 1996). Hughes et al (1994) proposed that there were 3 different strategies used to stand up; (1) the momentum transfer strategy, where the initial horizontal momentum is sufficiently large to bring the COM over the BOS; (2) the stabilisation strategy, where the subject moves the COM over the BOS whilst in the stable sitting position, using little or no horizontal momentum, and initiates vertical momentum in order to rise; (3) the combined strategy, where the COM is moved closer to the BOS prior to the initiating horizontal momentum of a relatively small magnitude. These 3 strategies directly relate to the control of balance during rising to stand.

No studies were found that directly addressed issues relating to the movement of the COM in relation to the BOS, during sitting down. It could be hypothesised that the requirement for precise voluntary control of the COM during sitting down is less essential than during rising to stand, as the movement ends in a relatively stable position with a large BOS. However, studies which have determined the time taken to rise to stand and to sit down have suggested that the time taken to sit down may be longer than the time taken to rise to stand (Engardt and Olsson, 1992; Durward, 1994). These results indicate that voluntary control is exerted over the movement of sitting down.

Although few studies investigating the control of the COM during rising to stand have been carried out exclusively to investigate balance control, the conclusions obtained from studies of rising to stand identify several implications for studies specific to balance. The relationship between the COM and the BOS, and the horizontal and vertical components of the COM movement, are critical to balance control. This indicates that division of the movement into an initial flexion (seat-on) and an ascending or extension (seat-off) phase may be particularly pertinent to the exploration of balance, as these phases successfully identify the movements in relation to the size of the BOS.

3.4.4 Weight distribution during rising to stand

A common assumption in investigations of rising to stand is that the weight distribution between the legs will be symmetric (Baer and Ashburn, 1995). Many studies of rising to stand have acknowledged that this assumption has been made (e.g. Rodosky et al, 1989; Pai and Rogers, 1990, 1991a,b; Hughes et al, 1994). There has been little objective investigation carried out to support or refute this assumption (Baer and Ashburn, 1995).

Durward (1994) reported the lateral symmetry of weight distribution in 120 healthy subjects (20-90 years) and 36 subjects with hemiplegia for rising to stand and sitting down. The measurement system recorded vertical forces under the heels, forefeet and arms. The lateral symmetry index that was derived utilised the sum of the heel and forefoot forces. The lateral symmetry for the healthy subjects was defined as "[weight on right / (weight on right + weight on left)]", which expressed the percentage of body weight beneath the right foot (Durward, 1994). The mean lateral symmetry for the healthy subjects, expressed as a percentage of body weight, was 49.2±4.5% for the ascending phase and 48.7±4.1% for the descending phase. The lateral symmetry index for the hemiplegic subjects was defined as "[weight on affected side / (weight on affected side + weight on unaffected side)]", expressing the percentage of weight under the affected limb. On the first test day the mean lateral symmetry index for the hemiplegic subjects, expressed as a percentage of body weight, was 39.3±13.7% for the ascending phase and 38.4±13.4% for the descending phase. There was no significant difference in the lateral symmetry for ascending or descending between the first and last test days. There was a significant difference between the healthy and hemiplegic subjects for the mean lateral symmetry during ascending ($p<0.005$) and descending ($p<0.005$). Durward (1994) compared the values for lateral symmetry of weight distribution in hemiplegic subjects with a number of clinical scores. This analysis demonstrated high correlation between the clinical assessment of ability to transfer weight over the affected leg in stance and the ability to transfer weight over a semi-flexed knee in stance with lateral symmetry during ascending and descending (Spearman's correlation coefficients - 0.75-0.90). Comparing clinical assessments of sitting and standing balance and gait with lateral symmetry during ascending and descending demonstrated much lower levels of correlation (correlation coefficients 0.41-0.79). This study therefore demonstrated that subjects with hemiplegia, on average, placed more weight on to their non-affected limb during rising to stand and sitting down. The degree of asymmetry of weight distribution during rising to stand and sitting down correlated with clinical scores of ability to weight transfer, but not with clinical scores of sitting and standing balance and gait, suggesting that symmetry of weight distribution is a valid measure of some aspects of balance ability but not others. The author concluded that the high correlation between the symmetry of weight distribution and the clinical assessment of weight transference was indicative of the validity of lateral symmetry in the clinical assessment of stroke.

The data collected by Durward (1994) was in agreement with earlier data determined by Engardt and Olsson (1992). Engardt and Olsson (1992) recorded weight distribution during rising to stand and sitting down using 2 force plates, in 16 healthy and 42 hemiplegic subjects, in an investigation of stroke patients' perception of weight bearing. The results demonstrated that there was a significant difference in the symmetry of weight distribution of healthy and hemiplegic subjects during rising to stand ($p<0.001$). The hemiplegic subjects distributed 37.5% of body weight to the affected leg and 62.5% to the unaffected leg: the healthy subjects distributed 48.7% of body weight to the right leg and 51.3% to the left. (Engardt and Olsson, 1992, illustrated the standard deviation from the mean weight distribution graphically, but failed to report the values in the text: the standard deviation from the mean is therefore not reported here). There was also a significant difference during sitting down ($p<0.001$), with hemiplegic subjects distributing 37.9% of body weight on the affected leg, and healthy subjects 50.5% body weight on the right. This study supported the assumption that healthy subjects have symmetrical weight distribution during rising to stand and sitting down, and demonstrated that hemiplegic subjects can have a high degree of asymmetry. Engardt and Olsson (1991a,b) measured symmetry of weight distribution in 40 stroke patients, as part of an investigation into training and feedback; and Engardt et al (1993) took measurements from 42 stroke patients in order to investigate the relationship between symmetry of weight distribution during rising to stand and sitting down and measures of functional outcome. These studies both identified that subjects with hemiplegia exhibited asymmetrical weight distribution during rising to stand and sitting down (Engardt and Olsson, 1991,a,b; Engardt et al, 1993). In addition Engardt et al (1993) emphasised the importance of symmetry of weight distribution, finding a strong correlation between symmetry of weight distribution during rising to stand and sitting down and functional ability ($p<0.001$).

Millington et al (1992) measured the forces under the feet during rising to stand (in addition to 2-D kinematic data and muscle activity) with 10 healthy subjects (69±3 years). Although the data itself is not reported, the authors stated - and demonstrated graphically - that there was little change in the medial and lateral forces under the feet during the movement, and that this implied symmetrical weight bearing during rising to stand. Baer and Ashburn (1995) used a 3-D movement analysis system, with markers at the shoulder, pelvis and heel, to assess rising to stand in 30 healthy subjects (aged 61.6±7.7 years). From the analysis the authors concluded that healthy subjects exhibit small amounts of trunk lateral flexion (mean range = 3.56°±0.14°), trunk lateral shift (mean range, at pelvis = 29.6±7.3mm; at shoulders = 36.1±12.6mm) and trunk rotation (mean range, at pelvis = 5.69°±1.69°; at shoulder = 4.83°±2.63°). Baer and Ashburn (1995) stated that the magnitude of these movements were small and were unlikely to be identified during observation of a subject.

In conclusion, symmetry of weight distribution is often assumed during rising to stand and sitting down. There is limited evidence to support this assumption and further research is required. Studies have demonstrated that subjects with hemiplegia exhibit asymmetrical weight distribution and that this may correlate with clinical assessments of weight transference ability (Durward, 1994) and poor functional ability (Engardt et al, 1993).

3.4.5 Problems with studies of rising to stand

In addition to the lack of definitions of the phases of the movement of rising to stand and sitting down, the methodology of studies can be very different. Table 3.16

illustrates the standardisation of parameters adopted by different researchers. Schenkman et al (1990) argued that strict standardisation of the initial subject position was essential to allow comparison between studies. Schenkman et al (1990) determined and implemented a highly controlled methodology for rising to stand. The seat height was adjusted to 80% of the subject's knee height, the ankles were placed in 18° of dorsiflexion and the feet were 4 inches apart. With their arms folded across their chest, subjects rose to stand to the time of a metronome at 52 beats/min, dictating that rising to stand occurred in 1.2s. This controlled method of rising has since been adopted for use by other researchers (Ikeda et al, 1991; Riley et al, 1991), despite criticism by other authors pertaining to the high degree of standardisation. VanSant (1990), in an invited commentary to the article by Schenkman, expressed concern with the strict standardisation of the movement. With reference to the restriction of arm use, by requiring that the arms maintain folded in front of the body throughout the movement, VanSant (1990) argued this was not a measure of normal rising to stand. VanSant (1990) also emphasised that natural variability in the foot position at the start of the movement has been demonstrated to vary with age (Wheeler et al, 1985), and that controlling foot position may be placing the subject in an unnatural starting position.

Study	Seat height	Foot position	Speed of ascent	Arms
Ada and Westwood (1992)	0.38m	"level and flat on floor"	as fast as possible	natural, but no arm rests on chair
Alexander et al (1989)	knee height	"lower legs at approximately 70° to the horizontal and the feet flat on the floor"	natural	measured using and not using
Baer and Ashburn (1995)	?	no restriction	natural	natural
Carr (1992)	lower leg length	standardised (but standardisation not stated in text)	natural	natural, restricted and augmented
Crosbie et al (1997)	110% of knee-floor length	?	to metronome (1.5s)	folded
Durward (1994)	0.46m	feet in centre position; restricted due to force plate position & size	natural	natural; use of arm rests optional
Engardt and Olsson (1992)	knee height	knee angle 100-105° with knees pointing straight ahead. Feet parallel and 10-18cm apart.	natural	natural
Fleckenstein et al (1988)	0.44m	knees flexed 105° or 75°. Foot "angle and base width" self-selected.	natural	not used
Hanke et al (1995)	0.45m	"on the floor in front of the chair"	fast, natural, slow	folded
Hughes and Schenkman (1996)	varied (lowest = 0.33m)	1st trial self-selected. Following trials as 1st.	natural	natural
Hughes et al (1994)	varied	1st trial self-selected. Following trials as 1st.	natural	folded
Ikeda et al (1991)	80% of knee height	ankles 18° dorsiflexion. Medial border of feet 10.2cm apart.	to metronome (1.2s)	folded
Kerr et al (1994b, 1997)	knee angle = 95-100°, and ankle 18°.	ankles 18° dorsiflexion. Heels 10cm apart	natural	folded
Kralj et al (1990)	self-selected	self-selected	natural	folded
Lee et al (1997)	knee angle 110° flexion	"parallel to the floor, 20cm apart and flat".	natural	folded
Magnan et al (1996)	knee height	1st trial self-selected. Following trials as 1st.	natural	folded
Mourey et al (1998)	100% knee height	ankles 20° dorsiflexion. Feet 10cm apart.	natural, fast	natural
Pai and Lee (1994)	0.45m	self-selected	fast, natural, slow	folded
Pai and Rogers (1990; 1991a,b)	0.45m	self-selected	fast, natural, slow	folded
Pai et al (1994)	0.45m	self-selected	fast, natural, slow	folded
Riley et al (1991)	80% of knee height	ankles 18° dorsiflexion. Heels 10cm apart Feet parallel.	to metronome (1.2s)	folded
Rodosky et al (1989)	65, 80, 100, and 115% knee-heel distance	"fixed location"	natural	folded
Roebroeck et al (1994)	knee height	Feet "next to each other".	to metronome	hands on hips
Schenkman et al (1990)	80% of knee height	Ankles 18° dorsiflexion. Feet 10.16cm apart Feet parallel.	to metronome (1.2s)	folded
Wheeler et al (1985)	0.44m	Self-selected	natural	natural

Table 3.16: Standardisation of parameters during rising to stand.

The view that strict standardisation and control during the analysis of rising to stand may reduce the natural variability, and hence the practical relevance, is supported by other researchers (Hughes et al, 1994; Baer and Ashburn, 1995). Schenkman et al (1990), Ikeda et al (1991), Riley et al (1991), Roebroeck et al (1994) and Crosbie et al (1997) all used a metronome to control the timing of the ascent to stand. However studies have demonstrated that the speed of rising can alter various parameters of the rising movement (Kralj et al, 1990; Pai and Rogers, 1990, 1991a,b; Pai and Lee, 1994; Pai et al, 1994; Hanke et al, 1995). The argument that control of the starting position and timing is essential to allow comparison between subjects (Schenkman et al, 1990), must therefore be disputed. Furthermore, authors have negated to investigate the reliability with which the controlled parameters can be implemented. Studies that have attempted to have subjects in strictly controlled starting positions do not state the reliability with which these positions are achieved. Despite this, it is generally assumed that the use of a strictly standardised protocol will increase the reliability of the measurements by reducing the number of parameters that can vary throughout the movement. The use of a tightly constrained protocol produces results that one could argue would be more repeatable than results from rising to stand using a less well standardised protocol. However, the argument proffered against the use of a tightly constrained measurement protocol relates to the validity of the measurement. Although the strictly standardised movement may reduce the variability between subjects and increase the reliability of the results, strict standardisation of the movement restricts the natural movement of the subjects. Strict standardisation may alter the manner in which a subject normally rises to stand or sits down to such a degree that the results are not a valid representation of normal rising to stand and sitting down for each subject or, therefore, for the population studied.

Rodosky et al (1989) demonstrated that changes in chair height significantly altered the flexion moments at the hip and knee ($p<0.05$). This study therefore illustrated that chair height can significantly affect components of the rising to stand strategy; subsequently data from studies using different chair heights is not directly comparable.

Shepherd and Koh (1996) found that different initial foot positions resulted in significant differences in the timing of the phases of the movement ($p<0.01$). Stevens et al (1989) demonstrated that changes in foot position caused significant differences in the horizontal and vertical components of head movement ($p<0.01$), and in the magnitude of the ground reaction forces ($p<0.01$). These studies suggest that studies that have placed restrictions on foot position may produce results that are not a valid representation of "normal" rising to stand. The COM/BOS separation has been identified to be central to balance control during rising to stand (section 3.4.3). Standardisation of foot position will place restrictions on the movement strategies for rising to stand.

Wretenberg et al (1993) demonstrated that hip and knee moments were significantly lower when using an arm rest than when rising unaided ($p<0.001$). As illustrated in Table 3.16, many authors have chosen to eliminate the use of arm rests and arm movement by requesting that subjects rise with their arms folded. It could be argued that the restriction of arm use would result in an unrepresentative measure of rising to stand. The results of this study lead to the hypothesis that the results of investigations that have eliminated arm use cannot validly be compared with studies that have allowed natural arm involvement.

In conclusion; there are no accepted definitions of the rising to stand or sitting down cycle, and the events and phases identified by different researchers are often incomparable. A debate regarding the standardisation and control of many of the variables in the rising to stand movement exists in the literature, and there is little consistency in the protocols adopted by different investigators. Whilst some authors argue that strict control is required in order to lessen variation between subjects and increase the reliability of the results, other researchers suggest that the variation between subjects may be an important measure of outcome or ability and that strict control of the movement reduces the validity of the measurement of the movement. Studies have illustrated that differences in chair height, foot position and armrest use can alter components of the rising to stand strategy. There is a need for valid, concise, definitions of the events occurring in the movement of rising to stand, and for the identification of a commonly adopted measurement protocol which will allow comparison between future studies.

3.4.6 Summary and conclusions

Since the 1970's investigation of the nature of rising to stand has been studied, principally using measurements of kinetic and kinematic variables and muscle activity. Research into the movement of sitting down has received little attention. Although the movement has been recognised as having horizontal and vertical components, and the horizontal control has been suggested to be central to balance during rising to stand, there are no definitive descriptors of the events or phases of the movement. Symmetry of weight distribution has been assumed during rising to stand, although there is presently little evidence to support this assumption. Further research of the movement of rising to stand and sitting down is required; however, to allow comparisons with other studies, common features must be identified and issues relating to standardisation must be addressed.

3.5 Balance and other functional activities

The previous sections have identified the necessity for balance in order to maintain the postures of sitting and standing, and in order to move between and within these postures. Balance has been identified to be a generic term, encompassing any activity carried out to prevent falling (Winter, 1995). Balance is therefore a prerequisite for all functional activities. Common to all tasks is the fact that in order to maintain balance the COM must be controlled with reference to the BOS. Balance control in sitting and standing, or during reaching activities, requires the maintenance of the COM within the BOS. Section 3.4 identified that during rising to stand and sitting down the BOS changes and the movement entails a degree of instability as the COM is moved from one BOS to the other. Winter (1995) identified that in activities such as walking the balance criterion changes, from one in which effort is made to maintain the COM within the BOS, to one in which the goal is to keep the COM outside the BOS and yet remain upright. Winter (1995) and Woollacott and Tang (1997) both confirmed that during walking the COM remains out of the BOS during the single-limb support periods. Woollacott and Tang (1997) hypothesised that the control mechanism for balance during walking must be different from the mechanisms used in activities where the COM remains within the BOS.

Wade and Jones (1997) stated that balance was a continuous process, which was present during all voluntary motor activities, and that control of balance was dependent on the activity being carried out and the environment in which it was carried out. Wade and Jones (1997) suggested that as balance control was a continuous process, studies that have investigated discrete tasks, such as standing, might not be applicable to the "real-world". At present there is little published research on balance control during more continuous, or dynamic, activities (Woollacott and Tang, 1997).

Woollacott and Tang (1997) suggested that human locomotion could be divided into 4 "sub-tasks":-

1) the generation of continuous movement to progress towards the desired destination;
2) the maintenance of balance during the progression;
3) the adaptability to meet contextual changes;
4) the initiation and termination of the task.

With the exception of the generation of the movement itself, each of the sub-tasks is directly related to the control of the COM, with reference to the BOS. Patla et al (1990) defined two mechanisms responsible for the balance control during walking. These were proactive and reactive control mechanisms; with proactive mechanisms occurring prior to any encounter with potential threats to stability, and reactive mechanisms occurring as automatic postural responses to quickly regain balance if the proactive mechanisms fail to detect and respond to a threat to balance (Patla et al, 1990). Maki and McIlroy (1997) expand this description of balance mechanisms to encompass all functional activities:-

> "The ability to regulate the relationship between the COM and BOS during activities of daily life results from a combination of reactive (compensatory) and predictive (anticipatory) balance control strategies. Whereas predictive control can serve to minimise the destabilising effect of predictable disturbances due, for example, to volitional movement, reactive control is the only recourse in the event of unexpected perturbation; hence, reactive control is likely to be of paramount importance in allowing stability to be maintained in the unpredictable circumstance of daily life."

Maki and McIlroy (1997) further divided the reactive mechanisms, into "fixed-support" and change-in-support strategies, which were "distinguished by the absence or presence of limb movement to alter the BOS".

It can, therefore, be concluded that the maintenance of balance is implicit to all functional activities, and relates to the control of the COM with reference to the BOS. Proactive control is used to anticipate and adjust for movements of the BOS or COM, while reactive control is used if the proactive mechanisms fail. Reactive control acts to regain balance by either returning the COM into the BOS, or moving the BOS. Although it has been recognised that balance control is a continuous process and is present during all motor tasks, the majority of studies of balance have concentrated on discrete motor tasks, and few studies are presently available on the maintenance of balance during more continuous tasks (Wade and Jones, 1997).

3.6 Implications for studies of balance and stroke

3.6.1 Measurements of balance and patients with stroke

Balance is a global concept, referring to the reaction of humans during three classes of function; the maintenance of a specified posture, the movement within and between postures, and the reaction to an unexpected disturbance. There are a number of different methods of measurement that have been used to assess balance during different functions. The validity of these different methods and the derived variables as assessors of balance has rarely been addressed. For any future research it is therefore imperative that the method of measurement selected has been considered with reference to the aspect of balance that is to be researched. Although the validity of the measurement of weight distribution during postures and movement has not been addressed, measurements of the symmetry of weight distribution during standing and during rising to stand and sitting down have been demonstrated to identify problems of postural control in subjects with hemiplegia following stroke. Studies have found that the symmetry of weight distribution in stance in subjects with hemiplegia correlates with measures of functional ability.

There are a lack of studies which have measured weight distribution in sitting, and there is little objective data available pertaining to sitting balance in subjects with hemiplegia. Despite the lack of objective data pertaining to sitting balance in subjects with hemiplegia following stroke, one of the key aims of physiotherapy treatment for patients with stroke is the improvement of balance in sitting. It is therefore vital that studies of sitting balance in this population are carried out. The problems of postural alignment in sitting, due to hemiplegia, lead to the hypothesis that measurement of weight distribution would be an appropriate and valid measure of sitting balance with the stroke population.

Measurements of weight-shifting are hypothesised to be a valid measure of ability to control the movement of the COM within the BOS, and thus reflective of balance. The review of the available literature led to the proposal that reaching to the side from a sitting position was a suitable method for producing a standardised protocol for the investigation of weight-shifting in sitting. Although there have been a lack of studies investigating weight-shifting through reaching in sitting, initial exploration of reaching from a standing position has demonstrated that this may be a valid measure of COM control in stance, and that measures related to reaching in stance correlate with functional ability. The validity of using variables directly related to the COP as outcome measures of reaching remains unknown. However, following the review of the literature it was proposed that measurements of weight distribution during reaching out from a sitting position might be valid and appropriate assessors of balance. Rehabilitation of balance following stroke commonly aims to improve patients' ability to control the movement of the COM within the BOS, and to have the ability to transfer weight from one side of the seat to the other, during sitting. Hence it is proposed that measurements of the transference of weight during reaching are appropriate measures of balance in patients with hemiplegia following stroke.

Thus, following a thorough review of the literature, it is proposed that objective measurements of the symmetry of weight distribution and the ability to transfer weight are appropriate measures of balance in patients with acute stroke. This conclusion is supported by Nichols (1997) who, following a review of the literature pertaining to balance retraining after stroke, concluded that measures of symmetry and movement within the limits of stability were more appropriate assessors of a patient's ability than measures of the COP.

Since patients with stroke can have balance problems during many functions, it will be appropriate to measure balance in stroke patients during a number of different postures and movements. It is proposed that measurements of balance during sitting, standing, rising to stand, sitting down and during reaching out from a sitting position may be reflective of global ability to balance in patients with acute stroke. It is hypothesised that the measurements of the symmetry of weight distribution during sitting, standing, rising to stand, sitting down, and reaching from sitting will be appropriate outcome measures for studies of the balance ability of patients with stroke.

3.6.2 Measurement systems and the assessment of weight distribution

The review of literature identified several common problems with the use of objective measurement systems during the study of balance. Many of these problems related to the failure of researchers to carry out the necessary calibration checks on the measurement equipment, and the subsequent failure to identify the accuracy, precision and reliability of the measurement tool. Any future research must address these issues adequately.

A problem specific to the measurement of symmetry of weight distribution is the selection of inappropriate indices of symmetry (Durward and Rowe, 1991). Durward and Rowe (1991) illustrated the problems of expressing symmetry data and highlighted the importance of selecting an index that would form the data into a normal distribution. Durward and Rowe concluded that the index A/(A+U), where A is the force through the affected side and U the force through the unaffected side, may be the most appropriate index to reflect changes in symmetry. The authors selected this index as it provided linearity, with a continuous scale from 0 to 1 and with the midpoint, 0.5, representing symmetrical weight distribution. However, it can be argued that a scale where values from 0 to 0.5 represent more weight on the unaffected side, and where values from 0.5 to 1 represent more weight on the affected side, can be difficult to interpret. A value of 0.3 and a value of 0.7 represent the same degree of asymmetry, but in opposite directions: this is not immediately apparent from the index. It is proposed that an alternative index, that has the advantages of the linearity and the normal distribution emphasised by Durward and Rowe (1991), but that provides data that is easier to interpret is:-

$$\text{Symmetry Index, SI} = \frac{(\text{weight on left} - \text{weight on right})}{(\text{weight on left} + \text{weight on right})}$$

Or, in the case of hemiplegic subjects:-

$$\text{Symmetry Index, SI} = \frac{(\text{weight on unaffected side} - \text{weight on affected side})}{(\text{weight on unaffected side} + \text{weight on affected side})}$$

This formula results in a symmetry index where 0 represents symmetrical weight distribution between the sides. 1 represents all weight distributed to the left, or unaffected, side. –1 represents all weight distributed to the right, or affected, side. Asymmetry to the left and right can easily be compared as the absolute value of the symmetry index represents the degree of asymmetry regardless of direction. For example, a symmetry index of 0.3 indicates that a subject has 30% difference in weight distribution between the sides with more weight on the left than the right. Conversely a symmetry index of –0.3 also indicates there is a difference in weight distribution between the sides of 30%, but that there is more weight on the right than on the left. It is proposed that this symmetry index is suitable for the investigation of weight distribution in subjects with stroke.

The requirements for a measurement system for the study of weight distribution in patients with stroke were therefore that it was accurate, precise and reliable and that it could produce the data necessary to calculate the symmetry index. Additionally the system had to be suitable for use in a clinical setting, with patients who had multiple problems resulting from stroke.

A measurement tool capable of the clinical measurement of the symmetry of weight distribution in standing and during rising to stand and sitting down was developed at Queen Margaret College, Edinburgh (Durward, 1994). This measurement system comprised vertical force measuring sections under the heels and forefeet and within the arms of the chair. Durward (1994) reported extensive tests of the calibration of this system, demonstrating that the system was valid and reliable. This system was successfully used in a clinical setting to collect data from patients with stroke (Durward, 1994). Thus, this measurement system met all the criteria for the use as the measurement tool for the study of weight distribution in patients with stroke, with the exception that it did not have the ability to assess weight distribution during sitting, or during reaching out from a sitting position. However, the addition of a further 4 vertical force measuring sections within the seat of the chair, could potentially provide an objective measurement system capable of assessing weight distribution during sitting, standing, rising to stand, sitting down and reaching from sitting. Thus the system developed by Durward (1994) could be modified to provide a measurement tool appropriate for the assessment of balance in patients with hemiplegia following stroke, through the measurement of the symmetry of weight distribution during sitting, standing, rising to stand, sitting down and reaching from sitting.

4. Motor learning

4.1 Introduction

Motor learning refers to the permanent acquisition of a physical skill. This chapter discusses motor learning with reference to the optimal methods of motor learning, the theories of how motor learning occurs, and the application of the theories of motor learning to individuals with neurological deficits.

Motor learning has been defined as

> "a set of processes associated with practice or experience that leads to relatively permanent changes in the capability for producing skilled action." (Schmidt, 1989).

Higgins (1991) described skill as a "form of competence", and emphasised that for an individual to be skilful at a task they must have the ability to achieve the goal consistently in a variety of conditions. A skilled action should achieve the desired goal with minimal energy expenditure (Schmidt, 1991). However, motor skill is not only reliant on the successful organisation of physical resources, but is also dependent on an unique interplay of cognitive and perceptual processes to support the motor behaviour (Lee and Magill, 1983; Higgins, 1991).

Motor learning cannot be observed directly, but can only be inferred from the observation of a person's performance (Schmidt, 1988; Magill, 1993). Performance is the level of skill acquisition that a person achieves (Marteniuk, 1979); the level of skill achieved may only be temporary. Thus a performance level is the quality of the execution of a skill at a certain point in time.

Motor learning is a permanent change in the level of skilled performance (Schmidt, 1988). Although motor learning cannot be directly assessed, it is indicated by observation of a performance which

a) improves over time

and / or b) becomes more consistent over time (Schmidt, 1988; Magill, 1993).
Often a "retention" test, or a series of retention tests, are carried out in order to assess performance and performance consistency over time (Schmidt, 1991). These are tests of performance that occur after the practice trials have terminated. It is now accepted that retention tests are essential in order to assess learning, and often these tests are continued over a prolonged period of time. However, despite the recognition of the importance of retention, there appears to be no available work that has explored the relationship between practice and retention time.

Research has been carried out into various aspects of motor performance and learning since around 1880 (Adams, 1987). Much of the early work was heavily based in behavioural psychology, and research concentrated on determining optimal methods for performance and learning, rather than addressing issues relating to theories of how the skills were learnt (Schmidt, 1987). Interpretation of many of the earlier psychology-based experiments is marred by their failure to carry out retention tests, thus providing data pertaining to motor performance rather than motor learning. More recent research has led to the acceptance that practice is fundamental to the acquisition of skill, and to successful motor learning (Marteniuk, 1979; Lee et al, 1991; Schmidt, 1991; Magill, 1993). Extensive studies have been executed to explore the many different parameters of practice, and the influence on motor learning. The results of these studies, and evidence pertaining to the function of the CNS, have led to the proposal of evidence-based hypotheses relating to motor learning.

The research into many areas of motor learning is extensive; subsequently the critique of all studies leading to evidence, hypothesis formation, or theories of motor learning is beyond the scope of this chapter. The following sections review evidence, hypotheses and theories of motor learning and mechanisms of motor learning with reference to the principal texts. Where extensive reviews of the available studies have been drawn by established authors, in text books and review papers, the reader is referred to these texts for more detailed information.

4.2 Optimal acquisition of motor skills

As has previously been identified, practice is fundamental to the acquisition of skill, and to successful motor learning (Marteniuk, 1979; Lee et al, 1991; Schmidt, 1991; Magill, 1993). Schmidt (1991) states that the two variables that are critical to the achievement of optimal motor learning are the practice itself and feedback regarding the success of the task practised. Extensive research has been executed to explore the many different parameters of practice and feedback strategies, and the influence on motor learning. The majority of these studies have involved the investigation of healthy individuals during the acquisition of a specific, discrete, novel task. The results of these studies have been central to the development of theories pertaining to the way in which motor skills are learnt. The following sections introduce some of the key evidence pertaining to the optimal acquisition of motor skills.

4.2.1 The task to be learnt

Central to a subject carrying out the practice required for learning a new motor skill is motivation (Schmidt, 1988, 1991; Magill, 1993). Despite a lack of experimental evidence, it is generally accepted that a subject must recognise the purpose of the motor skill and have a desire to learn it, in order to exert maximal effort into practice sessions (Schmidt, 1991; Magill, 1993). *Goal setting*, in which subjects set goals for themselves prior to practice, has been demonstrated to improve learning. Studies have shown that if subjects set themselves higher goals, they will achieve greater learning (Schmidt, 1991). Magill (1993) identified guidelines for goal setting aimed at optimising motor learning, based on the available literature. These guidelines suggest that:-

- goals aimed purely at mastering a skill lead to optimal performance and increased persistence at practice;
- objective, quantifiable, goals are more effective than abstract goals;
- goals must be meaningful to the subject;
- goals must be attainable;
- goals should be set according to the individual and their past performance levels;

- the provision of both short- and long-term goals is preferable to the provision of only one type of goal.

Once a subject is motivated to learn a new motor skill, Schmidt (1988, 1991) suggested that it is important that the subject is provided with an overview of the task to be performed. It was identified that this information can be portrayed via instructions and demonstrations (Schmidt, 1988, 1991; Magill, 1993). However there is a paucity of research carried out on the use of instructions to provide a learner with the correct idea of the task to be practised, or to improve the motivation of a learner to practice. Further research is required into this area.

4.2.2 Organisation of practice

Part vs. Whole Task Practice

Studies have investigated whether motor learning is greater in situations where the whole task is practised, or in situations where the task is divided into a number of component parts and these parts are practised in isolation prior to recombining them to make the whole. The concept of part vs. whole practice is central to the concepts of *transferability* and *specificity*. Transfer of learning refers to the degree to which practice of one task can result in a change in the ability to carry out a second task. If part practice is to be successful, transfer of the learning of the part-task must occur to the whole task. Specificity refers to the degree to which a movement programme for one task is related to the movement programme for another task. If each task practised requires a specific and independent movement programme then one could predict that part-practice will not assist in the learning of the whole task. Studies indicate that the benefits of part practice as compared to whole practice are dependent on the nature of the task to be learnt. Skilled motor tasks can broadly be described as either:-

- Discrete movements; where the task has a recognisable beginning and end.
- Serial movements; which are discrete movements strung together in a sequence.
- Continuous movements; which have no recognisable beginning and end.

Experimental evidence suggests that if a discrete motor task is practised in its' component parts there is little transfer of learning to the whole task (Schmidt, 1991). Studies have also indicated that part-practice of discrete tasks can be detrimental to the learning of the whole task (Schmidt, 1991; Magill, 1993). In contrast, studies have found that if the more complex parts of a serial movement are practised in part, then the execution of the whole task can improve (Schmidt, 1991; Magill, 1993). This has been found to be more advantageous when the parts are practised in sequence with the other parts of the movement. However, again in contrast, part-practice of a continuous task has not always been demonstrated to improve the learning of the whole movement (Schmidt, 1991). Experimental evidence suggests that if the component parts of a task occur simultaneously, overlap, or interact, then part-practice becomes less effective for learning (Schmidt, 1988). It is now generally accepted that practising a whole task is more advantageous for motor learning than practising a task in it's component parts (Marteniuk, 1979; Schmidt, 1988, 1991; Magill, 1993). The exception to this appears to be when a skill is extremely complex, when practising the whole task may hinder learning (Marteniuk, 1979; Schmidt, 1991; Magill, 1993).

Massed vs. Distributed Practice Schedules

A massed practice schedule is one in which the practice time is greater than the rest time between trials. A distributed practice schedule is one in which the rest time is greater than or equal to the practice time. Massed practice schedules have been found to cause a significant decrease in performance levels, as compared to distributed practice. However, studies using retention tests have found that massing does not effect learning to the same extent; some studies have even found that learning was greater following a massed practice regime than following a distributed practice regime (Schmidt, 1988). Magill (1993) highlighted the controversy in the literature pertaining to the use of massed vs. distributed practice schedules. Magill (1993) indicated that the results from research investigating continuous and discrete tasks appeared to be different. During the learning of continuous tasks, massed practice has been shown to have a variety of results. Some studies have shown that massed practice has a similar effect to distributed practice, while other studies have concluded that massed practice is detrimental to the learning of a continuous motor task. In contrast, research has demonstrated that massed practice can be more advantageous than distributed practice for learning discrete motor tasks.

The research investigating these practice schedules can be linked to some of the work that investigated the effects of practising in situations of fatigue. The inherent nature of massed practice results in greater fatigue than distributed practice. Fatigue has been found to have adverse effects on motor performance (Godwin and Schmidt, 1971; Carron, 1972). However, the evidence of the effects of fatigue on motor learning remains inconclusive. Some studies (e.g. Godwin and Schmidt, 1971) have found that motor learning improves in situations of fatigue; whilst others (e.g. Carron, 1971) have found that fatigue is detrimental. Magill (1993) suggests that continuous tasks can require greater energy expenditure and therefore induce more fatigue than discrete tasks. Magill (1993) has attempted to explain the differences in these results, by suggesting that there is a "threshold of fatigue": fatigue below the threshold will be beneficial to motor learning, fatigue above the threshold will be detrimental to motor learning. Unfortunately the methods of inducing fatigue in the different studies are not comparable, so no further support is available for this hypothesis.

Blocked vs. Random Practice Schedules

If a number of distinct skilled movements were to be learnt, a blocked practice schedule would involve repeated repetition of the same task prior to practise of the next task. A random practice schedule would involve randomisation of the practice of the tasks. Research indicates that, although blocked practice can result in better performance than random practice, random practice leads to better retention of learning (Shea and Morgan, 1979; Lee and Magill, 1983; Schmidt, 1988, 1991; Lee et al, 1991).

Variability in Practice

Variability in practice refers to the variation in the parameters of the actual movement skill being acquired. Thus the goal of each practised repetition would be systematically or randomly varied throughout the practice session. A varied practice schedule is distinct from a random practice session in that during random practice a number of individual tasks are practised, and during variable practice the tasks are all variations from the same class of movements. There is strong evidence that increased variability is beneficial for learning; no studies have found that increased variability is detrimental to learning (Schmidt, 1988).

Guidance

Guidance can be physical or verbal direction to a learner in order to reduce the number of errors during the performance of a motor task. Guidance has been demonstrated to substantially improve the performance of a practised motor task. However there is extensive experimental evidence which shows that guidance does not assist, and can be detrimental to, motor learning (Salmoni et al, 1984; Schmidt, 1988, 1991; Schmidt et al, 1989; Lee et al, 1990). This evidence has led to much support being given to the *"guidance hypothesis"*, which states that the guidance role of knowledge of results (see section 4.2.3) can force learners to rely on this feedback in order to be able to perform the task and that this inhibits learning from occurring (Salmoni et al, 1984; Schmidt, 1988, 1991; Schmidt et al, 1989; Lee et al, 1990).

4.2.3 Types of feedback

The term feedback refers to sensory information about a movement (Schmidt, 1991). Feedback is often divided into two broad categories:-

1. **Intrinsic Feedback.** This is information directly from the learner's sensory system that occurs as a consequence of the movement. This includes sensations such as touch and pressure, proprioception relating to joint position and muscle tension, vision and audition.
2. **Extrinsic Feedback.** This is information which comes from the environment; and not directly from the learner. This is often called "**augmented feedback**" as it occurs in addition to intrinsic feedback. It is augmented feedback that can be manipulated in an attempt to influence learning. Different types of extrinsic feedback have been classified in the literature. These include:-

a) Knowledge of Results (KR)

KR has been defined as extrinsic, or augmented, feedback, usually verbal (or verbalisable), which provides information pertaining to the success of a movement in relation to an environmental goal (Schmidt et al, 1989; Schmidt, 1991). KR often duplicates information that is available from intrinsic feedback mechanisms.

b) Knowledge of Performance (KP)

KP is extrinsic feedback pertaining to the movement pattern that the learner has performed. This is often referred to as "kinematic feedback", as it provides information about the movement or movement pattern (rather than the *outcome* of the movement, as in KR). Although KP is often verbal (e.g. "your arm needs to bend more"), it can occur in other forms such as videotape or graphic representation (Magill, 1993).

Care has to be taken with the categorisation of feedback into "intrinsic" or "extrinsic", as the differentiation between these types of feedback is not always distinct. For example, vision is a sensation said to provide intrinsic feedback; yet extrinsic (augmented) feedback is often visual in nature. It is perhaps less confusing to think of augmented and non-augmented feedback, which indicate whether the information has been given purposely, as additional information to augment the performance. The sub-categorisation of feedback into KR and KP also has limitations. Although definitions are frequently provided in the literature, KR and KP are often not differentiated in the research studies. The amount of research investigating KP is limited, due to the difficulty of providing consistent and correct KP. Thus research using KR is most often carried out, and it is frequently assumed - despite a lack of evidence - that the conclusions from the research are applicable to KP as well as KR. Although the terms KR and KP can be useful as descriptors, the classification is used infrequently in the literature. The term "feedback" is most commonly used as a broad descriptor.

4.2.4 Functions of feedback

Motivation

An important function of feedback is its' role in motivating the learner. Research investigating the provision of feedback during boring, repetitive, long duration tasks where performance was deteriorating, found that performance immediately increased with the provision of feedback (Salmoni et al, 1984). Feedback has also been found to increase the length of time for which learners will practice a task. Learners report that they find they work harder if feedback is provided (Schmidt, 1991). In this way feedback can also function as a major reinforcer. However, the research into feedback as a motivator primarily addresses the influence on performance and few retention tests to allow the investigation of learning have been carried out by the researchers in this field.

Information

Schmidt (1991) stated that the most important component of feedback for motor learning was its' role in the provision of information about the pattern of the required movement. Feedback provides information about errors in a movement; this leads to modification in the pattern of a movement in an attempt to correct for the errors and improve the performance. Continued feedback will tend to maintain performance errors at a minimum. However, although feedback has been found to increase performance, some research has found that increased feedback led to a decrease in the amount of learning (as explained by the "guidance hypothesis", section 4.2.2)

4.2.5 Parameters of feedback

Substantial research has been carried out into the effects of augmented feedback on motor learning. Similarly to investigation of the structure of practice regimes, the majority of studies exploring the parameters of feedback have involved the study of healthy individuals during the acquisition of a specific, discrete, novel task. Two categories of investigation of feedback can be identified; studies investigating the timing of augmented feedback (temporal aspects) and studies investigating the type of augmented feedback (nature of feedback). The temporal aspects of feedback include variables such as the frequency at which feedback is presented, and delays between task completion and feedback provision, the number of trials executed before feedback provision, the number of those trials for which feedback is provided, and the "averaging" of the feedback from a number of trials. The nature of feedback includes factors such as the precision of the feedback information; research has demonstrated that, up to a certain degree of precision, the more information that is provided the greater the effect on learning.

4.2.6 Summary and conclusions

Research has led to the assertion that practice is fundamental to motor learning. Many studies have been carried out which have explored parameters of practice and feedback with the aim of identifying optimal methods for the acquisition of new motor skills. Although there remain many areas that require further research, substantial evidence pertaining to the optimal parameters of motor learning is available in the literature. The current evidence identifies that, for the optimal acquisition of motor tasks,

- goals of practice should be to master a skill, and should be objective, quantifiable, meaningful and attainable.
- the whole task should be practised (except for extremely complex tasks);
- practice sessions should be distributed, random and incorporate variability;
- feedback should motivate, interest, and inform about errors, but too much feedback should be avoided;

Any future research investigating the learning of motor tasks should ensure that practice sessions are aimed at optimal acquisition, as indicated by the available research.

4.3 Theories of motor learning

The closed-loop theory of motor learning introduced the concept that the detection of error was central to learning (Adams, 1971). Following identification of the limitations of the closed-loop model, Schmidt (1975) proposed an open-loop model of motor learning ("Schmidt's Schema Theory").

4.3.1 Generalised Motor Programmes

Central to the idea of Schmidt's Schema Theory was the concept of generalised motor programmes. The concept of movements being programmed generally was first introduced by Pew (1974). Schmidt suggested that a generalised motor programme served as a memory representation for a class of movements, rather than for one individual movement. The theory proposed that a series of movements that have the same invariant characteristics belong to the same movement class. One generalised motor programme will represent this movement class. Experimental evidence suggested that relative timing, relative force, sequencing of events and spatial configuration of a movement are some of the "invariant" characteristics of a movement (see Magill and Hall, 1990, and Schmidt, 1991, for a review of these studies). Thus, if the relative timing, relative force, sequencing of events and / or spatial configurations of a task remain constant then variations of the task are all under the control of the same motor programme. Conversely, if the relative timing, relative force or sequencing of events in a task vary then control is considered to be from a different motor programme.

4.3.2 Recall and Recognition Schema

Schmidt's theory proposed that two states of memory - recall and recognition - are used by the learner to select the appropriate motor programme specifications that are used to produce the movement. The combination of the memory of the outcome of previous attempts and the knowledge of the specifications of the desired response result in the recall schema. Thus the recall schema involves the selection of the appropriate motor programme and the predicted specifications to achieve the desired outcome. This is based on the memory of past outcomes. The recall schema is structured in advance of the movement and does not involve any feedback during the movement. The memory of past sensory consequences combined with the actual sensory consequences constitutes the recognition schema. Thus the recognition schema is responsible for response evaluation, and detects if there is a mismatch between the expected and the actual sensory feedback.

Figure 4.1 illustrates the involvement of these process in Schmidt's schema of motor learning:-

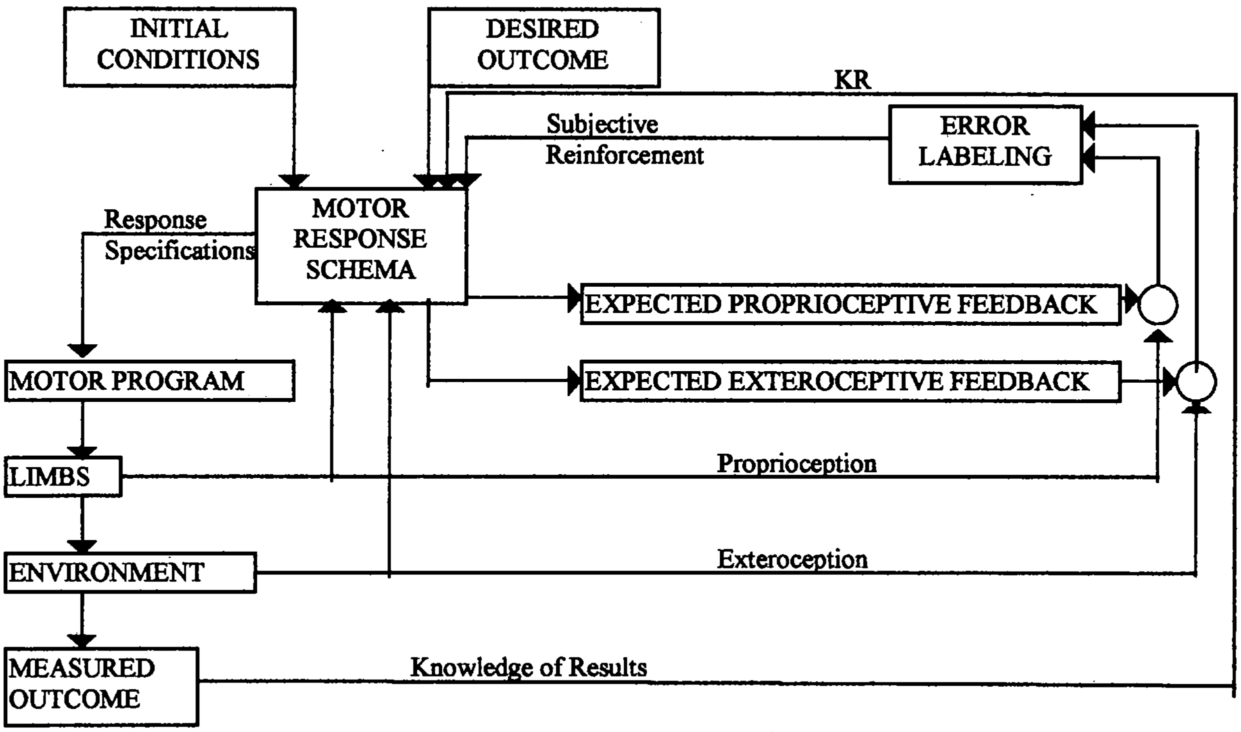


Figure 4.1 The motor response schema in relation to events occurring within a trial (recall and recognition schema combined for clarity). From Schmidt (1975)

4.3.3 Schema Learning

Schmidt proposed that an individual stores information pertaining to

a) the initial conditions; i.e. the conditions that existed prior to the movement, including body positions, environmental conditions, parameters of desired task (attempted distance, weight etc.);

b) the specifications of the generalised motor programme which was initiated;

c) the success of the movement; i.e. the outcome as dictated by the knowledge of results;

d) the sensory consequences of the movement; i.e. the exteroceptive and proprioceptive feedback.

This information is stored only long enough to enable the recall and recognition schema to be formed.

The involvement of the recall and recognition schema is therefore apparent. In order to perform a movement with minimal error the individual needs to have a representation of past outcomes, motor programmes, and sensory experiences. The more memory representation an individual has, or the more accurate the knowledge of the desired movement and sensory consequences, the greater is their ability to produce a movement with minimal error.

This theory predicts that in order to improve performance and to learn a motor skill, the motor response schema has to be initiated repeatedly to allow the learner to create the necessary recall and recognition schemas. Each repeated attempt at the movement should use the memory of the outcome and experience of the previous attempts to make alterations to the specifications of the motor programme, and to reduce the amount of error with each movement. This prediction that repeated practice of the movement skill is required in order to improve motor performance and learning is well supported with evidence from the literature.

Although not stated, the development of the recall and recognition schema implies the necessity for attention and cognition, which are also strongly supported by the literature.

4.3.4 Problems and Limitations of the Schema Theory

While there is much supporting literature for Schmidt's Schema Theory, and this theory provides an explanation for the results of many experiments into motor learning, the theory is limited by its' deductive nature. Central to the theory is the concept of the "generalised motor programme". Schmidt recognised that it remained "vague" how such a programme could be developed and used (Schmidt, 1988).

4.4 Neurophysiological processes of motor learning

The study of the functional organisation of neuroanatomical structures has led to evidence pertaining to the neurophysiological processes involved in motor learning. Although these processes are not yet fully understood, it has been proposed that the process of comparing the desired movement with the sensory feedback from the executed movement is central to motor learning (Kandel and Schwartz, 1985). Evidence suggests that the cerebellum acts as the comparator, playing a role in the regulation of the timing of the movement being trained. It has been proposed that long term cellular changes in the cerebellum occur when motor tasks are learnt, however this suggestion remains to be directly demonstrated and has been disputed (Kandel and Schwartz, 1985; Keele and Ivry, 1991; Gilman and Newman, 1992; Llinas and Welsh, 1993; Nolte, 1993; Jenkins et al, 1994; Schutter, 1995; Seeds et al, 1995; Bear et al, 1996; Raymond et al, 1996). Experiments have demonstrated that changes in afferent input result in long-term plastic changes within the cerebral cortex. These experiments have led to the proposal that the changes occur during the process of motor learning (Dobkin, 1993; Pascuale-Leone et al, 1994; Elbert et al, 1995; Karni et al, 1995; Lee and van Donkelaar, 1995; Rosenzweig and Bennett, 1996; Seitz and Freund, 1997). Thus, it is hypothesised that the process of motor learning involves a number of mechanisms within the CNS and central to these processes are changes in afferent input which result in long term plastic changes in the cerebellum and / or the cerebrum (Kandel and Schwartz, 1985; Gilman and Newman, 1992; Nolte, 1993; Bear et al, 1996).

4.5 Application of motor learning theories to individuals with neurological damage

In applying the theories of motor learning to individuals with neurological damage, there are three key questions that must be addressed:-

1. Can an individual with damage to the central nervous system learn motor skills in the same way as a healthy individual?

2. Is the learning of new motor tasks by a healthy individual analogous with the re-learning of movement skills that were lost due to neurological damage?
3. Are the neurophysiological processes of recovery and re-learning synonymous?

The first of these questions is intimately involved with information relating to the extent of the neurological damage in the subject. This question pertains to whether the subject maintains the neurophysiological processes necessary for motor learning. The research evidence on which the theories of motor learning are based is primarily related to the investigation of healthy individuals learning new motor skills. Following neurological damage a subject may require to *re-learn* a skill that had previously been acquired. The second question refers to whether re-learning a skill is comparable to learning a new skill. The final question relates to the process of rehabilitation following neurological damage. This point challenges the assumption that rehabilitation is an active process, involving cognitive learning by the neurologically damaged subject: does recovery involve the same neurophysiological processes as re-learning? There is a paucity of literature that addresses these research questions. The following sections will review the pertinent research.

4.5.1 Motor learning following neurological damage

Literature pertaining to motor learning following neurological damage can broadly be divided into two categories: 1) studies investigating the learning of abstract motor skills and 2) studies investigating the re-learning of functional skills as part of treatment program.

Learning of abstract motor skills

A number of studies have attempted to investigate differences in ability to perform motor tasks following left or right hemispheric damage. Although these studies principally investigate performance and fail to measure learning, they do present some interesting findings in terms of a patient's ability to perform a task before, during and after a period of training. These studies primarily use discrete, novel motor tasks. For example, Kimura (1977) investigated the effect of motor task training in 45 patients with hemiplegia following CVA. Patients with left CVAs were categorised as aphasic or non-aphasic. Subjects were instructed to carry out a hand function task, with a manual sequence box, using the unaffected hand. Subjects continued practising until they could successfully execute 5 repetitions of the task. The time for completing 5 successful repetitions, following demonstration of the task, was recorded. Kimura (1977) compared the ability of patients with left-hemisphere (n = 29) and right-hemisphere (n = 16) damage to perform the novel upper limb function. There was no difference between the hand strength and finger tapping ability of the two groups. This study found that patients with left-hemisphere damage had poorer performance (as determined by acquisition time, $p<0.001$; and errors in acquisition, $p<0.03$) during and after training than patients with right-hemisphere damage. The results led the author to suggest that the left hemisphere was responsible for "internal" spatial functions, which were to do with changing the position of one body part relative to the rest. Although this study did not compare the ability of patients with neurological damage with the ability of healthy individuals to perform a motor task, it does suggest that left-hemisphere damage resulted in impairment in the ability to improve one's performance with training.

Haaland et al (1987) compared the ability of patients with left-hemisphere (n = 10) and right-hemisphere (n = 9) damage to perform a motor task. Haaland et al (1987) also included two healthy control groups who either performed the task with their right (n = 10) or their left (n = 10) hand. The task was a tapping task, involving tapping two target plates. In support of the study by Kimura (1977), this study found that the patients with left hemisphere damage were impaired in their ability to perform the task. The ability of the patients with damage to the right-hemisphere was not impaired relative to the control group. However, Haaland et al were cautious in drawing conclusions from this study in view of the diverse findings and controversy surrounding the hemispheric control of motor functions (Haaland et al, 1987). They emphasise the need for further research.

Winstein and Pohl (1995) also found differences in the motor performance between subjects with left and right hemispheric lesions. 10 subjects with right hemiplegia, 10 with left hemiplegia, and 10 healthy controls carried out a tapping task. Subjects with left hemispheric lesions were found to have deficits relating to the timing and triggering of sub-components of the movement, while subjects with right hemispheric lesions were found to have deficits in processing and reacting to visual information (Winstein and Pohl, 1995). The results of this study concur with the studies of Haaland et al (1987) and Kimura (1977), demonstrating that motor control and performance is related to the side of hemispheric lesion in patients with stroke.

Rode et al (1997) suggested that the motor recovery of subjects with left and right hemispheric lesions was different. The authors investigated the postural control of patients with stroke and found that a lack of balance control persisted for longer in subjects with left hemiplegia. This led to the hypothesis that the right hemisphere was able to "compensate more readily for the postural deficit related to hemiplegia than the left hemisphere" (Rode et al, 1997). However, the use of only one measurement, rather than measurements over time, restricts the ability to draw conclusions pertaining to the recovery of the patients and the results found could potentially be due to the relative severity of the strokes of the subjects with left and right hemispheric damage.

Although these studies provide useful information regarding the ability for patients to *perform* motor tasks, they fail to address the ability of a patient to *learn* a motor skill. Platz et al (1994) attempted to address the question of the ability of an individual with neurological damage to learn motor skills to the same extent as healthy individuals. Platz et al (1994) investigated the ability of 20 individuals with motor control deficits (but no sensorimotor or cognitive deficits) following CVA, and 16 healthy controls, to perform and learn a "three-dimensional motor learning task" (comprising triangular movements with the hand in the air). The test-procedure was standardised and involved massed blocks of practice with and without feedback. The number of repetitions was kept low in order to prevent fatigue. A number of blocked-practice sessions were carried out during one day; on the following day a retention test was carried out. The results demonstrated that stroke patients did have the ability to use feedback from training aids, and to improve spatial performance. Compared to baseline values, after the training the variation of the mean velocity decreased ($p<0.01$); the drawn triangle resembled the correct shape more closely ($p<0.01$, $p<0.025$ and $p<0.01$ for angles of triangle); there was an increase in the duration of the break at the triangle corners ($p<0.001$); the variations of the movement iterations decreased ($p<0.025$) and there was a decrease in the mean velocity of movement ($p<0.01$). Although the motor performance of the hemiplegic subjects improved, the number of mistakes made by the hemiplegic subjects remained greater than those made by the control subjects ($p<0.001$) and the times taken by the hemiplegic subjects remained longer ($p<0.001$). The researchers suggested that the higher demand for time and for corrections to reach the desired behaviour goal by the stroke patients was indicative of a lower level of automation by stroke patients. Automation of motor control, economy and consistency were lower for all motor tasks; thus implying that stroke patients were less skilful than the control group. The retention test demonstrated that there were few lasting training effects, suggesting that the training improved some aspects of performance but not motor learning.

Saladin et al (1994) explored the effect of different frequencies of feedback pertaining to the achievement of target forces using the elbow flexors and extensors in 10 hemiplegic subjects. Retention tests demonstrated that subjects receiving feedback on 50% of trials had greater motor learning than subjects receiving feedback on 100% of the trials. This conclusion is in accordance with the evidence relating to the frequency of feedback and the guidance hypothesis derived from studies with healthy subjects.

Hanlon (1996) investigated the effect of blocked and random practice regimes on subjects with hemiplegia. 24 subjects (13 with right hemiplegia; 11 with left hemiplegia) were randomly assigned to a random practice, blocked practice or control group. A series of practice sessions were carried out (except for the control group), followed by 2 retention tests. The task performed was a 5-step functionally oriented upper limb motor task. There was a significant difference between the performance of the subjects carrying out random and blocked practice during both of the retention tests ($p<0.01$). However, analysis of the performance during the practice sessions demonstrated that there was no significant difference between the random and blocked regimes with respect to the rate of acquisition during the practice session. The authors concluded that random practice regimes were more effective for the learning of motor tasks (i.e. at retaining the task over time) for subjects with hemiplegia. This conclusion is in accordance with the research on motor learning for healthy subjects.

In summary; there have been few studies that have investigated the ability of subjects with neurological damage to learn new motor skills. The studies that have been carried out are limited by the failure to address issues relating to the distinction between performance and learning. Further research is required in order to address the question of whether subjects with neurological damage have the ability to learn new motor skills.

Motor learning as part of a treatment program

A number of studies have been carried out which have investigated the efficacy of treatment interventions for patients with neurological deficits (especially CVA). Although the motor learning literature emphasises the importance of both practice and the use of feedback for motor learning, the large majority of studies of treatment for patients with hemiplegia have principally investigated the use of feedback. The following review concentrates on studies specific to the learning of functions relating to balance by subjects with hemiplegia.

Winstein et al (1989) took measures of COP position and movement, and weight distribution, during stance in 40 patients with hemiplegia, before and after a 3-4 week treatment period. A further 21 patients then carried out a standing feedback training program for 30-45 minutes per day, 5 days per week for 3-4 weeks. The program involved receiving visual feedback responding to weight distribution, during training of stance, rising to stand, weight shifting and stepping in place. 21 of the initially measured control subjects were cross-matched with the 21 intervention group subjects, and their data compared. It is implicit that the control subjects carried out a regime of practice similar to that of the intervention group but without feedback, although this is not made clear. The results demonstrated that the motor performance had improved with feedback; with the COP position moving closer to the midline in the post-test by the feedback group than by the control group ($p<0.05$). The failure of the authors to include a test of retention prevents the identification of conclusions pertaining to motor learning.

De Weerdt et al (1989) investigated the effect of feedback on standing balance in subjects with hemiplegia. De Weerdt et al (1989) used 2 subjects with left hemiplegia in an ABAB single-case study design. Each of the 4 phases lasted 1 week, during which the subjects attended for 30 minutes of treatment each day. During the A phases the subjects received 30 minutes of EMG biofeedback for the arm - this was the control intervention. During the B phases the subjects carried out weight transference exercises with feedback relating to weight distribution, using the Nottingham Balance Platform (NBP). The mean balance coefficient (L/R) for 30 seconds of stance was measured twice during the week before intervention started (baseline tests), before and after each daily training session, and once per week for 5 weeks after the training (retention tests). The results demonstrated that there was no improvement in the balance coefficient before the intervention, or during the 1st A phase. In the 1st B phase there were "marked" improvements, which were sustained during the subsequent A phase and improved slightly during the final B phase. During the retention tests the balance coefficient was found to be "reasonably well sustained within normal limits". Although this study appears to suggest that training standing balance with feedback relating to weight distribution promotes motor learning, the use of only 2 subjects, the subsequent inability to apply statistical tests, and the inability to control for treatment in the weeks following the intervention, limit the power of the results.

Sackley et al (1992) and Sackley and Lincoln (1997) also investigated the effect of feedback on the improvement of standing balance. Sackley and Lincoln (1997) did not state that the results reported were from a previously reported study (Sackley et al, 1992). However the subject samples, study design and results are similar in both reports. 26 patients with hemiplegia were randomised into a group receiving visual feedback relating to weight distribution during stance, or to one that received a placebo computer program. Subjects attended a 20-minute training session (as part of a 1-hour treatment session) 3 times per week for 4 weeks. Weight distribution in stance, and motor and ADL function were assessed before and after the intervention period; and a retention test was carried out 8 weeks after the end of the training. Significant improvements were found in the performance of subjects in the feedback group, but not in the control group, between the beginning and end of the program. A test of retention demonstrated that the difference between the two groups was no longer significant after 8 weeks; this suggests that there was no difference in the learning between the two groups. The limitation of this study is that all of the subjects were receiving regular physiotherapy treatment and continued to do so after the end of the intervention period. The lack of difference at the time of the retention test may therefore be due to treatment given to the subjects following the intervention period.

Sackley and Baguley (1993) carried out an ABAB single-subject study with two hemiplegic patients. Both patients were randomly assigned to receive force-feedback pertaining to the symmetry of weight distribution as part of their physiotherapy treatment during the either the A or the B phase, and routine physiotherapy without the augmented feedback during the other phase. Each phase was carried out for 1 week, with weekly assessments of the motor and functional ability and objective measures of the symmetry of weight distribution. Retention tests were carried out during the 2 weeks subsequent to the treatment phases. The results for both the subjects indicated that the feedback training led to improved symmetry of weight distribution and that some of the effects of the feedback training were retained in the follow-up assessments. Although this study is limited by the inclusion of only 2 subjects, by the lack of information provided pertaining to the treatment intervention, and by the possibility of bias by the therapist treating the patients, this study does provide evidence that supports the benefits of augmented feedback. The design of this study, using an ABAB format and a series of retention tests, appears to be advantageous to the investigation of motor learning.

Engardt et al (1993) carried out a study to investigate the effect of auditory force feedback during the re-learning of the maintenance of symmetrical weight distribution during rising to stand and sitting down. This study randomly assigned 40 stroke patients (1 week to 3 months post CVA) to either a force feedback or a "repetitive training" group. Subjects in both groups practised rising to stand and sitting down for 15 minutes, 3 times per day, 5 days per week for 6 weeks. Subjects in the force feedback group received an auditory signal, via a strain gauged force plate, when the weight through the affected limb reached or exceeded a target level. Subjects in the repetitive training group were instructed to try to achieve equal weight distribution. The mean weight distribution during rising to stand and sitting down was recorded before and after the 6-week intervention period. The results demonstrated that there was a significant difference between the weight distribution before and after training for the force feedback group ($p<0.001$), but not the repetitive training group. However, Engardt et al (1993) failed to include any retention test. Thus, although Engardt et al (1993) found a significant difference in the weight distribution of the group receiving feedback, and not in the practice-only group, the failure to include any tests of retention means that these results only refer to motor performance and not to motor learning. Considering the available research evidence on motor learning and the optimal parameters of practice and feedback for healthy subjects learning new motor tasks, it is surprising that studies such as this one (Engardt et al, 1993) fail to acknowledge the available literature on normal motor learning. Engardt et al (1993) refer to "repetitive training", which is analogous with practice, as a "control", without acknowledging that practice has been demonstrated to be central to motor learning. Thus the study by Engardt et al (1993) has demonstrated that stroke patients receiving feedback on 100% of the trials have an improved performance as compared to stroke patients practising without feedback: this finding is consistent with the evidence relating to motor learning in healthy subjects.

McRae et al (1994) randomly assigned 30 hemiplegic in-patients to a control or to an experimental group. Throughout their hospital stay, the control group received standard physiotherapy treatment on 6 days per week, while the experimental group received the standard physiotherapy treatment on 3 days per week and received biofeedback aimed at improving balance on the other 3 days per week. McRae et al (1994) concluded that the biofeedback training resulted in improvements in standing balance and functional independence, but no improvement in gait performance. However, a lack of information provided pertaining to the study design and assessments limit the ability to draw conclusions from this study.

Hocherman et al (1984) and Carr et al (1997) both carried out studies that investigated the effects of practice, as opposed to the specific effects of feedback. Hocherman et al (1984) carried out a randomised controlled study to investigate the effects of training (practice) of standing on a moving platform on aspects of balance in stance. 24 patients with hemiplegia, who were 10-21 days post CVA and who were able to maintain stance on the moving platform for 2 minutes were recruited. Subjects were randomly assigned into a treatment (practice) group (n=13) or a control group (n=11). Subjects in the training group attended two 5-minute training sessions, 5 days a week for 3 weeks. The training involved standing on the moving platform; the amount of movement being determined by the stability of the subject. The maximum movement amplitude (MMA) that subjects could withstand for 2 minutes was measured before and after the 3 weeks of training for both the control and training group. The weight distribution between the legs was also determined. Analysis demonstrated that the change in the mean MMA between the two readings was greater for the training group ($p<0.0025$). The ratio of the final MMA to the initial MMA was also greater for the training group ($p<0.05$). The authors stated that the weight distribution between the legs improved more for the training group than the control group; however the level of significance reported did not support this claim ($p<0.1$). This study suggests that practice of a balance task may promote re-learning of that task. However, the failure of the authors to carry out a test of retention means that this claim cannot be substantiated. In addition, the low numbers of subjects, the short time period since the onset of hemiplegia, the failure to include a placebo treatment, and the use of the same equipment for both the treatment and the testing, limit the power or these results. Although the authors suggested that this training program resulted in changes in weight distribution, the significance level did not support this claim: the ability to generalise from this specific training programme must therefore be challenged.

Carr et al (1997) explored the effect of a 3 week training program aimed at improving biomechanical features of rising to stand in 6 patients with chronic stroke (at least 1 year post CVA). The lack of details provided pertaining to the training program prohibit the analysis of the program based on the available literature. However the authors demonstrated that features of rising to stand improved with training and concluded from the pattern of results that the change in performance was due to improvement in timing and co-ordination rather than to muscle strengthening. Despite the lack of study details, the low number of subjects and the absence of tests of retention, this study does suggest that the motor performance of patients with stroke can be improved with training.

These few studies all emphasise the limitations of the research done into motor re-learning following neurological damage. There appears to be a general failure to recognise the large body of motor learning literature and to draw on the available evidence pertaining to healthy subjects. This failure has resulted in the production of a number of studies that have not included tests of retention, which are vital in the research of motor learning. Many investigations of feedback have been carried out; however few of these studies have made reference to the evidence in the motor learning literature pertaining to the "guidance" effect of feedback. The assumption of the majority of researchers investigating treatment for patients with neurological damage appears to be that 100% feedback will be beneficial to learning. The guidance hypothesis challenges this assumption. It is essential that researchers carry out studies of motor learning with subjects with neurological damage; however, it is vital that the hypotheses being tested by these studies reflect the available motor learning literature.

4.5.2 Motor re-learning and motor learning

If the motor learning theories are to be applied to a rehabilitative setting, then the theories are to be applied to a subject who requires to re-learn an old skill (e.g. the ability to walk) as opposed to learning a new skill. The issue of whether the learning of a new skill is analogous with the re-learning of an old skill has had little discussion in the literature. In a review of the physiological mechanisms of recovery, Lee and van Donkelaar (1995) stated that

> "The learning of new motor skills with an intact CNS and the recovery of previously learned motor skills that have been lost following localised damage to the CNS appear to be similar in several respects. In each case, the movements are initially highly variable and inaccurate, but with time and practice they become much more controlled and precise. The underlying neurophysiological modifications responsible for these behavioural changes may be the same for motor learning and for recovery of motor skills following brain injury."

However, Lee and van Donkelaar (1995) provided scanty evidence in support of this statement, referring to animal experiments that suggest that motor learning involves the long term adaptation of synapses within the motor cortex. The authors stated that "whether analogous processes underlie recovery of motor function following stroke is open to speculation". This review therefore, while addressing the questions relating to the possible similarities in the mechanisms of learning and re-learning following stroke, fails to determine a conclusion.

Memories pertaining to the desired movement outcome and expected sensory consequences are central to the process of motor control and learning. When learning a new motor skill, the learner will have no previous memory representation. In contrast, when re-learning an old skill, it could be hypothesised that a significant memory representation may still exist. However, whether the old memory representation, with a representation of the motor programs and pathways previously used to execute the movement, is beneficial or detrimental to re-learning is unknown. Authors have rarely addressed the issue regarding relearning as opposed to learning. Mulder (1991) described rehabilitation therapy (following spinal cord injury) as "the (re)-acquisition of action schemata". Mulder provided a set of rules pertaining to rehabilitation therapy but does not expand on the concept of (re)-learning versus learning. Similarly, Winstein et al (1989) referred to balance "retraining", but did not expound on the issue of *re*-learning or *re*-training.

A recent study appears to have provided the first direct experimental evidence that addresses issues relating to re-learning as opposed to learning. Nudo et al (1996) trained a number of squirrel monkeys at a skilled motor movement (a hand function). Using intracortical microstimulation techniques maps of the motor cortex were derived. Focal infarcts of the motor cortex hand area were then induced. Five days after the induction, the monkeys were restarted on a training program identical to the previous one. The pre-infarct performance level was achieved after 3-4 weeks of training. Repeat mapping of the motor cortex demonstrated that the representation of the hand had invaded the adjacent areas that had previously represented the elbow and shoulder. An earlier, similar, study (Nudo and Millkin, 1996, in Nudo et al, 1996) which had not involved any training, found no adaptation to the motor cortex map. These results from animal experiments suggest that re-learning of a motor skill can occur following focal neurological damage, through use of a training program. However it is hypothesised that the mechanism of relearning, which was demonstrated to involve cortical reorganisation (Nudo et al, 1996), cannot involve the same processes as learning a new skill for the first time, with an intact neurological system. Thus, while these experiments (Nudo et al, 1996) demonstrated that re-learning occurred through re-training, there is no direct support for the hypothesis that learning and re-learning involve the same physiological mechanisms.

Further studies of the motor re-learning ability of both healthy and neurologically damaged subjects are essential.

4.5.3 Motor re-learning and motor recovery

Motor learning has been demonstrated to be a process reliant on practice and requiring active cognitive involvement to compare the desired and the consequent movement. The assumption has been made by some rehabilitation therapists (Carr and Shepherd, 1989) that rehabilitation involves the re-learning of skills. Neurophysiological texts generally refer to "recovery" following neurological damage. However, the legitimacy of the assumption that recovery from neurological damage involves the active re-learning of motor skills, rather than the recovery of the pre-injury skills, has to be addressed.

Although it is accepted that recovery, sometimes substantial, can occur following damage to the CNS, the neurophysiological mechanisms of recovery are not fully comprehended (Devor, 1994; Sabatini et al, 1994; Caramia et al, 1997). It is recognised that immediately after a CNS injury recovery can occur in response to the reduction in oedema, the resorption of necrotic material and the improvement in local circulation (Bach-y-Rita, 1981b; Chollet et al, 1991; Dombovy, 1991). However the period in which these factors can contribute directly to functional recovery are limited (Wall, 1980; Bach-y-Rita, 1981b; Dombovy, 1991). Following these initial processes, further recovery is thought to occur through structural reorganisation of the nervous system (Dombovy and Bach-y-Rita, 1988; Dombovy, 1991; Devor, 1994; Good, 1994; Illis, 1994). The neural reorganisation of the central nervous system is referred to as "plasticity". A number of different neurophysiological mechanisms have been proposed to result in plastic changes within the nervous system.

Damage to one area of the brain can result in a decrease in neuronal input to areas of the brain which were not themselves damaged but which previously received input from the damaged area ("diaschisis") (Dombovy, 1991; Cohen, 1993; Devor, 1994; Good, 1994). Diaschisis therefore causes depression of neuronal input and a loss of function in areas of the brain other than the damaged area. Parts of the brain generally receive inputs from many other areas of the brain. Miyai et al (1997) investigated the functional outcome of 46 patients with strokes, classifying patients according to the site of the lesion. Patients with stroke confined to the basal ganglia were found to have significantly poorer functional ability 3 months after stroke. The authors suggested that this was due to diaschisis, with many areas of the CNS with neuronal connections with the basal ganglia degenerating. However, there is increasing evidence that an adjustment of the relative weight of the remaining, intact, inputs to the depressed area may occur and the function of that area may be re-established (Devor, 1994; Good, 1994). Thus functional recovery may occur through the resolution of diaschisis (Dombovy, 1991; Good, 1994), although the ability for this to occur may be dependent on the site of the lesion (Miyai et al, 1997).

Two mechanisms of neural plasticity have been termed sprouting and unmasking (Illis, 1994). Sprouting refers to the growth from intact cells toward and into the damaged area of the brain in response to a functional demand, after some or all of the normal input to that area has been removed (Bach-y-Rita, 1981b). It has been proposed that the ability of sprouting to beneficially contribute to motor recovery is limited (Giles and Clark-Wilson, 1993), as adjacent areas of the brain are often responsible for differing tasks and sprouting between neighbouring areas may bring inappropriate information to the damaged area (Bach-y-Rita, 1981b; Dombovy and Bach-y-Rita, 1988; Dombovy, 1991). Dombovy (1991) stated that experimental evidence suggested that "repetitive functional demand or training in specific activities" could aid recovery by promoting beneficial neuronal sprouting. Unmasking refers to the initiation of use of neural pathways which have previously been in existence but not previously used for the new function (Wall, 1980). It has been demonstrated that when a nerve cell loses its' original input, these nerve cells develop the ability to respond to new inputs which previously had no effect (Dombovy and Bach-y-Rita, 1988; Illis, 1994). Unmasking can occur at any time when the input to the nerve cell is altered (Dombovy, 1991; Illis, 1994). Unmasking can therefore occur without damage to the neurological system.

A further mechanism of plasticity is the process of neurological substitution. This is a process where, if one neural input is lost following a lesion, adjacent parallel neurones may be able to readjust and take on the role of the lost function. A number of studies have identified that there can be substitution between the hemispheres, where the intact hemisphere acts to manage motor and sensory control bilaterally (Bach-y-Rita, 1981a; Chollet, 1991; Kawamata et al, 1997). It is not yet known to what extent neurological substitution aids in the process of recovery following neurological damage (Seitz and Freund, 1997). It has been proposed that the involvement of the process of sensory substitution may be dependent on the type and degree of neurological damage. Netz et al (1997) found that focal transcranial magnetic stimulation of the unaffected hemisphere resulted in ipsilateral motor evoked responses at significantly lower thresholds of stimulation for stroke patients with poor recovery than for stroke patients with good recovery. This finding supports the hypothesis that plastic changes can occur in the hemisphere contralateral to the lesion, and suggests that this may be dependent on the degree of neurological damage (Netz et al, 1997). Caramia et al (1997) have also recorded ipsilateral motor evoked responses from stroke patients, while these were not recorded from healthy subjects. Caramia et al (1997) concurred that the findings provided evidence of plastic reorganisation following stroke and were of potential interest to the field of rehabilitation following stroke. However the motor recovery of the arm in the 13 patients involved in the study was reported to have occurred spontaneously, without physiotherapeutic intervention (Caramia et al, 1997). This challenges whether physiotherapeutic intervention can effect plastic changes, or whether these changes will occur regardless of intervention.

The plastic changes occurring in response to a CNS lesion appear to happen in direct response to the localised area of damage, or decreased synaptic input from the area of damage to neuronal cells. Although there is substantial evidence to show that recovery from a CNS lesion can occur through plastic changes in the brain, the processes that effect or enhance this neural plasticity are not fully understood. The degree to which recovery of motor functions will occur spontaneously, and the degree to which training and active cognitive involvement can assist the process, must therefore be questioned (Bach-y-Rita, 1981b). Dombovy (1991) asserts that there is likely to be more than one mechanism of neurological recovery. Illis (1994) suggested that the ability to produce plastic changes through the alteration of afferent stimulation from the periphery had major implications for the rehabilitation of individuals with neurological deficits. While this statement stresses the potential influence of external factors on recovery, it does not address whether a patient must be an active participant in the process of recovery or whether recovery will occur if the patient is a passive recipient of altered peripheral input. However, experimental evidence has led authors to hypothesise that repetitive functional demand or training in specific activities can influence plastic changes (Dombovy and Bach-y-Rita, 1988; Dombovy, 1991). This hypothesis suggests that the process of recovery from neurological damage and the process of motor learning may be similar, with repetition of a motor task central to the neuronal changes. Following a review of the mechanisms of plasticity, Devor (1994) concluded that

> "What capacity we do have for functional recovery after CNS injury appears to be an unintended side-effect of plastic mechanisms designed to serve other ends, the most prominent being: (i) neural development; (ii) the ongoing calibration of internal representations; and (iii) the learning of new skills. These are the pillars upon which efforts at rehabilitation need to be built, and in these spheres the brain is intrinsically and exquisitely labile."

Thus Devor (1994) is supporting the hypothesis that the processes of recovery following neurological damage are intimately involved with the processes of motor learning. This leads to the hypothesis that recovery and re-learning may be comparable in terms of the neurophysiological processes involved. Extensive reviews of the experimental evidence have led several authors to support this hypothesis (Dobkin, 1993; Lee and van Donkelaar, 1995; Rosenzweig and Bennett, 1996; Seitz and Freund, 1997). Further research is necessary to investigate these hypotheses.

4.6 Summary and Conclusions

Motor learning is the permanent acquisition of new skills. Practice and feedback are fundamental to motor learning. Substantial research has identified that motor learning can be optimised if the parameters of practice and feedback are systematically designed and administered as indicated in the literature. It is essential that any future studies of motor learning are based on the available evidence pertaining to the optimal learning of new motor skills.

Theories and hypotheses of the mechanisms involved in motor learning have been proposed, although the details of the neurophysiological processes have not yet been established. Studies that have attempted to investigate whether subjects with neurological damage maintain the necessary processes to learn new motor skills have been inconclusive due to problems with study designs. However, it has been demonstrated that individuals with neurological damage can re-learn skills acquired before the injury through the processes of practice and feedback. Additionally, evidence relating to the mechanisms of recovery suggests that recovery may be influenced by repetitive functional demand or training in specific activities. This suggests that the process of learning a new skill may be comparable to the process of the functional recovery of a skill following neurological damage.

5. Physiotherapy following stroke

5.1 *Historical Review*

Prior to the 1940s, physiotherapy for patients with neurological deficits consisted primarily of corrective exercises, based on orthopaedic principles, aimed at the re-education of muscles. These techniques were principally based on the observation of the problems relating to contraction and relaxation of muscles. Emphasis was placed on regaining function by compensating with the unaffected limbs (Ashburn, 1995; Partridge, 1996). Subsequently, the realisation that problems following neurological damage were related to the nervous system, and not directly to muscular elements, initiated the development of a number of treatment techniques broadly based on the available neurophysiological knowledge (Ashburn, 1995). The physiotherapy techniques which emerged during this period included the Bobath approach (Davies, 1985; Bobath, 1990), the Brunnström approach (Brunnström, 1970), the Rood approach (Goff, 1969) and Proprioceptive Neuromuscular Facilitation (PNF)(Knott and Voss, 1968). These treatment approaches dominated the rehabilitative scene until the 1980s when the lack of evidence for the existing models of treatment, the importance of knowledge relating to neuropsychology and motor learning, and the potential application of this knowledge to the rehabilitation of individuals with movement deficits, was identified (Turnbull, 1982; Anderson and Lough, 1986). At this time, a model based on a review of the available knowledge relating to movement science was proposed by Carr and Shepherd (1989a). This approach has been named the Motor Learning, or Relearning, approach (Carr and Shepherd, 1987, 1989a,b, 1992).

In an attempt to identify which of the advocated treatment approaches were being used in Sweden for the treatment of patients with stroke, Nilsson and Nordholm (1992) carried out a questionnaire study. Questionnaires related to the training of the physiotherapists, the bases for their choice of treatment and any post-qualification courses attended were sent to all 213 members of the Neurological section of the Swedish Physiotherapy Association: 66% of these were successfully returned. The results showed that 40% of the physiotherapists had been trained in the Bobath approach; 26% in PNF; 11% in Brunnström; 4% in Carr and Shepherd; 1% in Davies; and 18% had received other training or had been trained in more than one approach. A systematic relationship was found between the year of completion of training and the method of treatment taught. Questions about post-qualification training demonstrated that 59% of the physiotherapists had attended some training; comments revealed that Bobath courses were seen as the most important technique to learn. While this study produced some interesting data, care should be taken in generalising these results.

Carr et al (1994) repeated the study carried out by Nilsson and Nordholm (1992) using a sample of Australian physiotherapists, and the questionnaires developed by Nilsson and Nordholm. All 331 members of the special interest group in neurology in Australia were sent questionnaires; 208 (72%) were successfully completed and returned. 40.1% of the respondents had been taught more than one treatment approach; over 90% of these physiotherapists had been taught the Bobath approach; around 80% PNF and around 40% the Movement science (Carr and Shepherd) approach. As in the study of Swedish physiotherapists, a systematic relationship was found between the year of completion of training and the treatment method taught. Carr et al (1994) found that, in general, PNF treatment dominated in the 1960s and the Bobath approach in the 1970s. The Bobath approach was joined by the Movement science approach in the 1980s. The two questionnaire studies (Nilsson and Nordholm, 1992, and Carr et al, 1994) concurred that the Bobath approach to treatment appeared, at that time, to be the most widely used by physiotherapists, with the use of the Movement science (Carr and Shepherd) approach increasing since 1980. Lennon (1996) agreed that the Bobath concept was the most common approach to treatment for patients with stroke, stating that the approach had "gained international acceptance as one of the leading approaches in stroke rehabilitation".

Sackley and Lincoln (1996) investigated the treatment approaches for stroke adopted by physiotherapists within the Trent Region of the UK, using a questionnaire based on the study carried out by Nilsson and Nordholm (1992). 121 senior physiotherapists involved in the treatment of patients with stroke received the questionnaire; 91 (75%)

were completed and returned. 80% of the therapists "always" or "very often" used the Bobath Approach; only 4% "always" or "very often" applied motor learning principles. The primary reasons given for using the Bobath Approach were related to the facilitation and production of "normal movement", while the Motor Learning Approach tended to be used if there was "poor progress with alternative". The therapists following the Bobath Approach were unable to explain the reasons for the effectiveness of the approach and none identified the theoretical basis behind the approach (Sackley and Lincoln, 1996). The results of the study by Sackley and Lincoln (1996) were in agreement with those of Nilsson and Nordholm (1992) and Carr et al (1994), concluding that the Bobath Approach was the most widely used physiotherapy treatment approach for patients with stroke.

Historically physiotherapists have treated patients using approaches that have not been evaluated scientifically. Sackley and Lincoln (1996) highlighted that this has become part of the "professional culture" for physiotherapists and proposed that, in addition to scientific evaluation of the techniques used in the treatment of patients with stroke, a "change in culture" was necessary for the implementation of evidence-based practice.

5.2 Bobath Approach to stroke rehabilitation

The Bobath approach was developed by Berta and Karl Bobath; observation and practical experience with individuals with neurological damage led to treatment techniques that were then related to the available neurophysiological evidence. Central to the Bobath concept is the assumption that neurological lesions can result in increased tone and reflex activity, through a decrease in the inhibition from the higher centres (Bobath, 1990). It is assumed that abnormal tone will result in abnormal movement (Bobath, 1990). Techniques involve the manipulation of kinaesthetic and tactile input in order to facilitate more normal movement (Davies, 1985; Bobath, 1990). Treatment based on the Bobath concept therefore involves manual handling of the patient by the therapist in an attempt to control the postural tone and allow normal patterns of movement to occur (Ashburn, 1995). The patient will be moved through specific sequences of movement, which are intended to prepare the patient for later functional activities (Davies, 1985). In a description of the process of rehabilitating a patient using the Bobath approach, Davies (1985) stated:-

> "From the beginning the patient, his trunk and extremities, need support and must be guided along natural patterns of movement to provide him with natural perceptive stimuli. The therapist quickly feels the patient perceiving a resistance, recognising it more readily, taking over and then learning the practised movement. Finally he will reach a point where integration takes place. If we work in natural, physiological appropriate movement patterns the patient will learn through repetition and will make constant progress."

Bobath treatments aim to improve the quality of movement on the affected side of the body, so that the two sides of the body can work in concordance (Bobath, 1990). Based on hypotheses regarding neurophysiological plastic changes in the CNS following neurological damage, the Bobaths proposed that plastic changes could be influenced, by therapists, through the manipulation of kinaesthetic and tactile input (Bobath, 1990). This proposal was based on hypotheses suggesting that intact afferent channels were the most important feature for the successful learning of motor functions (Davis, 1985). Davies (1985) suggested that it was possible for therapists to "unblock" previously unused neural pathways by bombarding them with suitable kinaesthetic and tactile information. This kinaesthetic and tactile input can be provided by the therapist by manually guiding the patient through patterns of "normal movement" (Davies, 1985; Bobath, 1990). It is not made explicit in the approach whether other forms of afferent input, in addition to the manually guided movements, are purported to assist in the facilitation of normal movement (Lennon, 1996). Lennon (1996) identified that there was no evidence to support the use of manual guidance to the exclusion of the use of other afferent inputs.

The original treatment methods advocated by the Bobaths were altered following increased clinical observation and experience, and led to the proposal of different treatment techniques (Bobath, 1990). Bobath (1990) identified that the treatment principles changed, but argued that the underlying concept remained unaltered.

Davies (1985, 1990) also adapted and refined the Bobaths' original treatment, creating a treatment approach "based on the concept of" the Bobath approach. Nilsson and Nordholm (1992) referred to 'Davies' treatment as a separate entity to 'Bobath' treatment; however this distinction is refuted by other authors (Carr et al, 1994). In the American literature the treatment based on the Bobath concept is also described as "neurodevelopmental treatment (NDT)" (Lennon, 1996). Wagenaar et al (1990) described NDT as the "modernised version of Bobath" and suggested that NDT was the approach presented by Davies (1985). However, Ashburn (1995) observed that the term "neurodevelopmental" was misleading, as the treatment was for adults and was not therefore associated with the developmental process. Partridge (1995) recognised the changes in the techniques of treatment which have been advocated over the years, and concluded that "what is practised within the overall concept can vary considerably".

A key feature of the Bobath approach is that there is no prescribed treatment and the treatment for each individual patient will be different (Davies, 1985; Bobath, 1990). The flexibility within treatments is anticipated as being very large: Bobath (1990) emphasised that "there is a great deal of experimentation in good treatment", suggesting that treatment not only differs between patients but will also differ within treatment sessions with individual patients. Lennon (1996) identified that the lack of standardisation in the treatment based on the Bobath approach created difficulty in evaluating the effectiveness of the treatment principles.

Treatment based on the Bobath concept involves a patient being moved through "normal" patterns of movement by a therapist (Davis, 1985). Success of this treatment is stated to be due to the experience of "normal" movement by the patient (Bobath, 1990). Despite the emphasis on manual guidance there is a lack of evidence that demonstrates that therapists can successfully facilitate "normal" patterns of movement. The ability to provide the sensation of normal movement during a facilitated movement is challenged by the results of a study that demonstrated that the kinematics of head and trunk movement of 20 healthy children were significantly different during induced and self-induced lateral tilt in sitting (Milette and Rine, 1987).

Additional problems relating to the interpretation of the Bobath approach lie in the use of language and terms that are specific to the approach. Lennon (1996) described the treatment based on the Bobath approach as requiring handling "via keypoints of control"; using "reflex inhibiting patterns"; and voluntary movement occurring through the "central postural control mechanism". The lack of written material means that definitions for these parameters are not commonly available. Sackley and Lincoln (1996) highlight that although the techniques and concepts related to the Bobath approach appear to have changed over time, these techniques have not been written down or published. This lack of literature is the principal problem in critically reviewing the Bobath approach and the evidence for the purported treatment techniques. Descriptive texts of the treatment approach are available (Bobath, 1978, 1990; Davies, 1985, 1990, 1994); but, as has been previously identified, techniques advocated in the earlier texts do not necessarily concur with the techniques described in the later texts. Despite the assertion that the Bobath approach is based on neurophysiological evidence and theories, the relationship between the treatment techniques and the neurophysiology of recovery is not adequately addressed in any text. Many of the texts describing treatment principles fail to address the neurophysiological basis for the treatment in any detail (Davies, 1990, 1994). Thus, although it is frequently assumed that the Bobath approach is based on sound scientific observations and theories (Keshner, 1981), there is a paucity of literature to support these assumptions. A further problem which is serving to perpetuate the lack of literature is that the Bobath approach is generally taught via oral postgraduate courses (Lennon, 1996). In addition to the problems directly related to oral dissemination, individual interpretations of the approach by the tutor can substantially influence the knowledge and beliefs adopted by the therapists attending the course (Valvano and Long, 1991). Although it could be argued that the tutors of the approach would be ideally situated to address the problems of the lack of literature, this has not occurred and it has been alleged that tutors are "reluctant to publish their work" (Valvano and Long, 1991).

One of the few available articles which attempts to address the physiological basis of recovery following neurological damage is an exploration of the physiological mechanisms involved in the reduction of spasticity (Musa, 1986). Musa (1986) reviewed the available theories of spasticity and neurophysiological control of movement and attempted to relate these to the techniques purported by physiotherapists. Musa (1986) was unable to find any literature which directly supported the techniques described by Bobath, yet by creating hypotheses based on the neurophysiological evidence was able to suggest:

> "that there is sufficient evidence to justify the use of techniques that are concerned with the manipulation of peripheral or afferent input to retrain normal movement in patients with spasticity (see Bobath, 1980) although much more evidence is needed to place the techniques on a scientific base".

The failure of many authors to relate the neurophysiological theories to practice is emphasised in a descriptive paper by Borgman and Passarella (1991), which attempted to apply the Bobath principles to the nursing care for patients with stroke. Although the authors briefly described the "plasticity theory of the brain, the unmasking theory and the collateral sprouting theory", there was a failure to relate the neurophysiological theories to the practical principles being described. Borgman and Passarella (1991) argued that

> "Normal movement is facilitated by Bobath nursing care because the neurophysiologic and neurodevelopmental concepts of movement and function are understood by the nurse providing care"

However, the evidence cited by Borgman and Passarella does not support this argument. Borgman and Passarella (1991) concluded that

> "Because the Bobath nursing approach is based on neurophysiologic and neurodevelopmental theories, there is a theoretical basis for research designs".

However, there is no evidence in the literature that supports this statement. Although the neurophysiological basis for the Bobath approach is frequently referred to, there is a lack of material that relates the neurophysiological evidence to the attested treatment techniques. Work is essential to relate the techniques of the Bobath approach to sound scientific neurophysiological evidence. Although the Bobath approach has been found to be the most widely used approach in the treatment of patients with stroke (Nilsson and Nordholm, 1991; Carr et al, 1994; Sackley and Lincoln, 1996), it has been recognised that the therapists using the approach tend to be unable to identify the scientific rationale for this approach (Sackley and Lincoln, 1996).

In a review of the Bobath concept, Lennon (1996) recognised that, although the neurophysiological theories pertaining to the plasticity of the CNS had been proposed as the rationale for the Bobath approach, these theories could also be used to explain the majority of other treatment approaches for stroke. The Bobath approach appears to have failed to have incorporated scientific theories from fields other than neurophysiology, and has not included knowledge from fields such as behavioural psychology and theories of motor control and learning (Lennon, 1996). Lennon (1996) identified that Bobath therapists have been criticised for not following motor learning principles and allowing the patients to practice functional tasks outside therapy sessions: however Lennon subsequently contended that "proponents of the Bobath concept would argue that this is a misinterpretation of the concept." If such misinterpretation is occurring, this can be ascribed to the failure of the proponents of the concept to express the approach in a clear and indisputable manner. Lennon (1996) concluded that

> "The major criticisms of the concept are that it relies too much on neurophysiology to the detriment of other systems which account for movement dysfunction".

The description of the Bobath approach, which involves the therapist moving the patient through patterns of movement, implies that the therapist acts as the problem-solver and decision maker, while the patient remains the passive recipient of the treatment (Lennon, 1996). This is in direct contradiction with alternative approaches that emphasise the importance of active involvement by the patient (Carr and Shepherd, 1989). However, although it opposes the written evidence on the approach, many proponents of the Bobath concept deny that the patient has a passive role during treatment (Lennon, 1996).

In summary; the Bobath approach involves the manual handling of a patient by a therapist in order to guide the patient through patterns of normal movement. The theory proposed in support of this approach is that the manipulation of afferent input can influence plastic changes within the CNS. Treatments based on the Bobath concept have varied over the years, and there has been a failure to publish written evidence for the approach. More recently the approach has been criticised for the failure to incorporate knowledge from scientific fields other than neurophysiology. Evaluation and research of this approach, which is purported to be the most commonly used approach in the treatment of patients with stroke, is essential. However, the ability for evaluation and scientific research remains limited until adequate written material and testable hypotheses have been formed.

5.3 Motor Learning approach to stroke rehabilitation

The Motor Learning approach was developed following the recognition that the treatment approaches for patients with neurological deficits were based on neurophysiological and medical theories, and did not encompass the rapidly increasing body of knowledge pertaining to the neurosciences (Carr and Shepherd, 1987). The model of treatment proposed by Carr and Shepherd (1987, 1989a, 1992) was developed using a deductive approach, basing the model on scientific evidence, using research from all available scientific fields (neurophysiology, medicine, biomechanics, behavioural science). The key proposal of the model was that individuals with neurological deficits would achieve functional recovery through an active process of motor learning. This model of treatment, which is described in detail in the literature, has been called the "Motor Relearning Programme" (MRP) (Carr and Shepherd, 1987), the Motor Learning Model (Carr and Shepherd, 1989a, 1990), and the "Movement science" approach (Carr et al, 1994). As in earlier treatment approaches, the model has also been described using the name of the originators, 'Carr and Shepherd' (e.g. Nilsson and Nordholm, 1992). However Carr et al (1992) stated that

> "Carr and Shepherd have argued that scientifically based rehabilitation should replace the previously dominant person-oriented approaches. There is, in effect, no Carr and Shepherd treatment approach. They have merely provided some leadership in proposing this change".

This concept will be termed the 'Motor Learning' approach in all subsequent sections.

Thorough review of the literature associated with movement science led to a knowledge base from which inferences regarding the analysis and training of the movement of a disabled individual could be made (Carr and Shepherd, 1989a). Review of the scientific literature led to the opinion that

> "The unique contribution of physiotherapy to the rehabilitation of stroke lies potentially in the training of motor control based on an understanding of the kinematics and kinetics of normal movement, motor control processes and motor learning." (Carr and Shepherd, 1987).

The Motor Learning approach was built upon the assumption that, following neurological damage, an individual can regain motor control through an active 'learning process'. It is assumed that the process of motor learning used by a healthy individual learning a new motor skill is equivalent to the process of re-learning a skill lost following neurological damage (Carr and Shepherd, 1987, 1989a,b, 1990). The scientific process is fundamental to the Motor Learning approach. The use of the approach must involve the initial analysis of the performance of a particular task, and the identification of problems or missing components; the training of the selected task; and the re-evaluation of the performance of the task after training (Carr and Shepherd, 1989a). Treatment based on this approach therefore involves the assessment of movement and identification of missing movement components, using biomechanical principles, followed by practice of the missing components by the patient, using all the principles available in the literature that are related to motor learning in healthy subjects.

Carr and Shepherd (1987, 1989a, 1990) carried out extensive reviews of the literature concerned with motor learning. They then followed a deductive process in order to develop a practical application for the theoretical knowledge in the area of motor learning. However, the research into motor skill acquisition has primarily focused on healthy individuals (Winstein, 1991). Carr and Shepherd chose to apply their theoretical application of the motor learning research to individuals who had suffered neurological damage, with special reference to stroke. Carr and Shepherd identified that the tendency for the motor learning research to concentrate on healthy individuals resulted in the inability to conclude whether the research was applicable to individuals with neurological deficits. Similarly Winstein (1991) emphasised that the "boundaries" of the theories relating to motor learning were not known. Carr and Shepherd (1989a) and Winstein (1991) stated that the major assumption of the application of the motor learning theories to individuals with neurological deficits was the assumption that these individuals retained the ability to learn motor skills through practice.

The treatment approach based on the theoretical knowledge concerning motor learning is therefore based on an assumption for which there is a lack of evidence. Despite the development of a treatment approach based on the scientific literature there is still scanty evidence to support the legitimacy of the assumption that individuals with neurological damage are able to learn the motor skills which have been adversely affected by the neurological damage. Controlled studies of motor learning and recovery of individuals with neurological deficits are essential to ascertain the legitimacy of the assumption on which the Motor Learning approach is reliant.

5.4 Efficacy of different treatment approaches

The majority of treatment approaches for stroke patients, with the exception of the Motor Learning approach, have been developed through an inductive process, resulting in techniques with a "rather questionable scientific basis" (Illis, 1994). A number of studies have been carried out in order to compare the efficacy of these different treatment approaches. This section reviews the available studies.

5.4.1 Amount of treatment

One of the key questions to be asked regarding physiotherapy for patients with stroke is whether active rehabilitation promotes greater recovery of function than "natural" recovery with no intervention. Smith et al (1981) carried out a randomised trial to address this question. From a total of 1094 patients admitted to an area hospital over a 6-year period, there were 121 (11%) who were discharged from hospital with significant motor deficits but healthy enough for intensive rehabilitation. These 121 subjects, and a further 12 outpatients (who met the same criteria but had not been in-patients) were recruited. After discharge from hospital (or admission into the trial) the patients were assessed on their functional ability to execute a number of activities of daily living (ADL). The patients were then randomly assigned to an intensive rehabilitation group (4 whole days of treatment per week), a conventional rehabilitation group (3 half days of treatment per week), or a group receiving no rehabilitation. ADL was assessed again at 3, 6 and 12 months after entry into the trial. The results demonstrated that there was a significantly greater improvement in the ADL score of the patients in the rehabilitation groups than of those in the group receiving no rehabilitation, between entry and the assessment after 3 months ($p<0.01$). Between entry and the assessment at 1 year there was a significantly greater improvement in the ADL score of the patients in the intensive rehabilitation group than in the group receiving no rehabilitation ($p<0.05$). Smith et al (1981) concluded that outpatient rehabilitation was effective in improving the recovery of individuals with stroke. The results indicated that intensive therapy was more advantageous, and that the beneficial effect was largely achieved in the first 3 months and, although it was maintained, did not increase in the following months. The major limitation of this study was that the therapists taking the assessment of the ADL score were not blind to the treatment group of the subjects; this may have created bias in the assessments. Treatment intensity was assumed to be related to the length of time that an individual spent at the hospital as an outpatient. Data was not provided regarding the proportion of time during which treatment was administered, or regarding the type of treatment given. A control group was not included to account for the possible beneficial effects of the attendance at a hospital, where positive influences such as increased socialisation may have occurred. This study only used 11% of the originally identified population: the ability to generalise the results of this study to other sections of the population must therefore be questioned. Similarly, the validity of using a small number of subjects from another population and including them in the study must be challenged. Although this study demonstrated that physiotherapy intervention was beneficial, the ability to generalise conclusions from this study to other situations is limited.

Smith et al (1982) carried out a randomised controlled trial to investigate the beneficial effects of a specialised stroke unit in comparison to a general medical unit. Patients presenting with strokes were randomly admitted to either a stroke unit or one of 12 medical units. Of the 155 patients admitted to the stroke unit, 125 (81%) survived until the follow-up at 60 days after admission. 152 patients were admitted to the medical units, and 109 (72%) were alive 60 days after admission. Tests of ADL function, mental function, proprioception, motor function and communication were carried out at discharge using standardised measurement tools. The results demonstrated that significantly more patients admitted to the stroke unit had achieved independence in ADL at discharge ($p<0.05$). 62% from the stroke unit and 45% from the medical units were independent at discharge. Although the study results implied that stroke units were more beneficial to outcome, and the authors provided data pertaining to the amount of therapy sessions received by the patients in the stroke and medical units, the authors identified that the results were limited due to potential bias in the data collected. The bias occurred as the testers were not blind to the unit which the patients had attended. In addition there was a lack of detail available pertaining to the specific treatment which subjects received, as the authors considered that the obtaining of such information might have influenced the treatment provided. Smith et al (1982) concluded that further studies of different therapy approaches were required.

A number of studies have compared the outcome of stroke patients admitted to a specialised stroke unit with the outcome of stroke patients admitted to generalised medical wards. A recent systematic review of the randomised trials of stroke unit care has been carried out (Stroke Unit Trialists' Collaboration, 1997a). This review concluded that stroke patients who are admitted to stroke units were less likely to die, to remain physically dependent or require long-term institutionalised care (Stroke Unit Trialists' Collaboration, 1997a). Stroke Unit Trialists' Collaboration (1997a,b) identified that the meta-analysis of randomised studies could not prove which features of stroke unit care effected the difference in outcome, but speculated that this may be related to therapeutic intervention time and strategies. Lincoln et al (1996) carried out a study that determined the activities carried out by stroke patients, who were in-patients either on a stroke unit or on a conventional hospital ward. Structured observation of 76 randomly selected patients (39 on stroke unit, 37 on general wards) demonstrated that patients on the stroke unit had significantly more interaction with nurses and therapists than patients on the general wards ($p<0.001$). It is proposed that this may account for some of the differences between outcome of patients from stroke units and general wards (Lincoln et al, 1996). However this study also found that the patient contact time with physiotherapists and occupational therapists was extremely low; being, on average, 36 minutes / day for patients on the stroke unit. Little activity, with no reports of self-practice of motor tasks, was observed out with the therapy time (Lincoln et al, 1996). The ability of physiotherapy to have any therapeutic effect on recovery after stroke when such a small proportion of a patient's time is spent participating in motor activities must be challenged.

5.4.2 Type of treatment

Stern et al (1970) carried out a study that compared PNF with conventional physiotherapy. 62 patients with hemiplegia due to cerebral infarct were randomly assigned to one of two treatment groups. The "control" was described as receiving no "specialised" intervention; and comprised heat and cold treatment for the shoulder, passive movements, and walking training within parallel bars, or with an aid. The "special specific therapeutic exercise program" included the same heat, cold and passive movement treatment as the control group; but, in addition, this group also received exercises based on PNF. Outcome was assessed using measures of mobility, strength and functional ability. No significant difference was found in the mobility, strength or functional ability of the patients in the two different treatment groups. While this study may have been potentially influential at the time of publication, the changes in the types of treatment now advocated by physiotherapists mean that the "conventional" treatment investigated would no longer be considered as conventional. The standardisation, reliability and validity of the parameters of this study must be questioned; however this does not detract from the importance of this study as one of the first controlled trials of therapy interventions. The finding that there appeared to be no difference in the efficacy of two different treatments highlighted many important questions regarding physiotherapy interventions for individuals with neurological damage.

Logigian et al (1983) attempted to compare treatments that were based on the "traditional (Kendall, Clayton and Coulter) approach" and the "facilitation (Rood, Bobath) technique". Despite the provision of references, this comparison immediately invites confusion as the approaches described by Rood and Bobath are not analogous. However, the authors stated that:-

> "In order to standardise the treatment modalities the OT [occupational therapy] staff of 24 were divided into 2 groups, each assigned the task of defining the therapeutic exercise techniques. Once a consensus was reached, all OT and PT [physiotherapy] staff were instructed in the facilitation and traditional exercise therapies."

Facilitation was described as focusing on the total body rather than its' component parts, and using the modification of afferent input to encourage movement. The traditional approach was defined as the strengthening and developing of motion, and the maintenance of passive range of movement. 42 stroke patients (less than 7 weeks since the onset of hemiplegia) were randomly assigned to either of the treatment approaches. Each of the patients received 30 minutes of physiotherapy and 30 minutes of occupational therapy daily, based on the assigned treatment approach. The Barthel index and upper extremity muscle strength were assessed on admission into the study and on discharge from hospital. A significant improvement was found between the pre- and post-tests ($p<0.05$). No significant difference was found between the two treatment groups. However the treatment provided is further complicated by allowing the physiotherapists to use facilitation techniques "on the lower extremities during gait training activities" regardless of the treatment group to which they were assigned. The ability of therapists to only use the technique on the lower limb is in direct contradiction to the earlier assertion that facilitation must focus on the whole body rather than on individual body parts. In addition, the ability of the therapists to use one technique to the exclusion of the other must be challenged. Logigian et al (1983) failed to identify the identity of the assessors: if the therapists carrying out the assessments were involved in the treatment of the patients, or knew the treatment group to which the patient had been assigned, the assessments may contain bias. The authors did acknowledge that the use of only two assessment tools, which could be argued to lack sensitivity, might be responsible for the lack of difference in the results.

Dickstein et al (1986) carried out a study designed to compare the effects of 3 specific techniques of treatment. 196 hemiplegic patients who were referred consecutively to a rehabilitation hospital (on average, 16 days after admission to an acute hospital with a stroke) were included in the study. 131 patients completed the 6-week program of treatment. Each of the patients was randomly assigned to one of 13 physiotherapists. Each of the physiotherapists was familiar with 'conventional' treatment (training the patient to use their unaffected side), PNF and the Bobath approach: refresher courses on PNF and the Bobath approach were provided and there were weekly meetings between physiotherapists in order to allow discussion regarding the treatment approaches. Each of the physiotherapists treated their first 5 patients with conventional treatment, the next 5 with PNF and the next 5 with the Bobath approach. In each case treatment was administered 5 days per week for 30-45 minutes. Sensory functions, the Barthel index, muscle tone, active ROM at the ankle and wrist, and ambulatory status were measured every 2 weeks for the 6 week treatment period. The results demonstrated that there was no significant difference in the scores for sensory function, the Barthel index, muscle tone or active movement at the wrist and ankle between the patients in any of the treatment groups, at any of the assessment times. The only significant difference found was in the walking ability at 2 and 4 weeks; less patients receiving Bobath treatment were able to walk at these times ($p<0.03$ and $p<0.04$ respectively), than were patients in the other groups. However, there was no difference before treatment or after 6 weeks of treatment. This study suggests that there was little difference in the functional outcome of patients receiving treatment based on different treatment approaches. The authors identified that the results of the study were limited by the arbitrary choice of 6 weeks of treatment and the subjectivity of the measurement scales. In addition the results may be limited by bias due to the measurements being taken by the physiotherapists providing the treatment. The ability of physiotherapists to provide treatment based solely on one theoretical approach, when they are familiar with and have been actively using, other treatment approaches must be challenged. The lack of difference between the subjects could be hypothesised to be due to an inability by the physiotherapists to provide treatment that was specific to one treatment approach.

Lord and Hall (1986) carried out a retrospective study of the effect of different rehabilitation approaches on long term outcome. Two rehabilitation centres were identified which both used different treatment approaches - one used "traditional functional retraining (TFR)" and the other "neuromuscular re-education techniques (NRT)". A generalised summary of these two approaches was provided in table form. 19 TFR and 20 NRT subjects, who had all had a stroke more than 8 months previously, were identified from a review of the in-patients in the two rehabilitation centres. The subjects, or a family member, were then asked to complete a telephone questionnaire, which involved the ranking of functional skills on a 4-point scale. A repeatability study on the responses of 8 participants, over a 2-week period, demonstrated a high correlation for each patient ($p<0.0001$). The authors found that there was no significant difference between any of the outcomes except the average length of stay in hospital, for the administered treatment. The NRT patients were found to spend significantly longer in hospital than the TFR patients ($p<0.001$). However, the authors identified that it cannot be assumed that the difference in the length of hospital stay is due to the treatment as there were a number of differences in the rehabilitation centres and their approaches. Lord and Hall (1986) proposed that extraneous factors such as the outpatient follow-up facilities could have influenced the length of hospital admission. Furthermore, although a repeatability study on the questionnaire was performed, this was only carried out on subjects in the TFR group. The questionnaire was administered by an occupational therapist to patients in the TFR group, and by a physiotherapist to patients in the NRT group. Thus the repeatability study only addressed the repeatability of the results gathered for one of the groups of patients and not the other. The reliability of the two assessors cannot be assumed to be the same. Other problems with this study included the failure of Lord and Hall (1986) to provide any references in support of the approaches described, or to discuss issues regarding the training and experience of the therapists who provided the patient treatment. There were several differences in the treatments provided in the different rehabilitation centres, such as the length and number of physiotherapy and occupational therapy sessions, which could have influenced the outcome. Comparing the functional ability of patients attending different rehabilitation centres in this manner does not therefore provide a valid method for the comparison of theoretical treatment approaches.

Basmajian et al (1987) attempted to compare the effects of treatment based on the Bobath approach with biofeedback using EMG (EMGBF). Basmajian et al (1987) randomised 29 patients who met a series of inclusion criteria, over a 3-year period, into a group which received EMGBF for the arm, or a treatment aimed at improving arm function based on the Bobath approach. The authors failed to describe the Bobath treatment. The EMGBF and the Bobath treatment were both applied by the same two physiotherapists. A validated upper extremity functional test, a finger oscillation test and an emotional functioning (health belief) assessment were carried out. The results demonstrated that the upper extremity function and finger oscillation improved over the treatment time ($p<0.001$), but there was no significant change in the health belief model. There was no significant difference between the EMGBF and the Bobath approach for the pre or posttest scores. Basmajian et al (1987) concluded that:

> "EMGBF compared favourably with traditional exercise therapy based on Bobath techniques given over the same time periods. Our present extended study suggests that the functional recovery following a formal behavioural approach (including biofeedback and cognitive therapy) is probably equal to, but not superior to, a matched program of Bobath-based PT. The results of 'hands-off' versus 'hands-on'

therapy in this controlled study of a selected population is impressive in that both approaches were clinically effective".

The assessments carried out may have been biased, due to knowledge of the treatment group by the testers or the assessments may not have been sufficiently sensitive to identify changes in ability. However, the improvement of both groups of subjects at similar rates does indicate that the approaches are similar in their outcome. As Basmajian et al (1987) recognised, it is surprising that two such different approaches should have the ability to produce such similar results. Further research is required to investigate whether these results are repeatable.

Wagenaar et al (1990) used a single-case study design to compare the relative efficacy of the NDT ("modernised" Bobath) and Brunnström approaches to treatment. 7 patients, 5 with right hemiplegia and 2 with left, were included in this ABAB study of treatment approach. The NDT approach was defined as being that presented by Davies (1985), while the Brunnström approach was as explained by Brunnström (1970). Both of the treatment approaches were carried out by the same therapists, who had been specially trained and had received a written protocol on the approaches. The first treatment provided was alternated for different patients, with each patient receiving 5 weeks of treatment in each of the stages of the study. Assessments were carried out weekly, using a number of validated assessment tools. These included tests of upper limb function, walking ability, ADL, depressive mood and feelings, and neuropsychological factors. The results demonstrated that there were no differences between the two treatment approaches for any of the assessments, with the exception of 1 of the 7 subjects when the Brunnström approach was found to exert a possible intervention effect on some gait parameters (no significance levels were provided). The authors argued that this difference might have occurred as a direct result of the specific walking training given in the Brunnström approach. The authors concluded that there are no clear differences between NDT and Brunnström, although they hypothesised that the lack of difference could be due to factors such as the short period of the intervention phase. The low number of subjects in this study reduces the ability to generalise from these results.

Sunderland et al (1992) compared "conventional" therapy with an "enhanced" regime that included increased treatment for the hemiplegic arm. 132 in- or out-patients who were consecutively referred for rehabilitation following stroke, and who met strict inclusion criteria, were randomised (using a stratified procedure) into either the conventional or enhanced therapy groups. The authors stated that the conventional therapy was based on the Bobath approach; yet "texts by Bobath and Johnstone" were both referred to. The Bobath and Johnstone approaches are generally considered to constitute two different therapy approaches. The enhanced therapy group received more intensive therapy for the arm, while the amount for the leg was stated to remain similar to that given to the conventional group. In addition the authors stated that the enhanced therapy group was encouraged to be active rather than passive in their treatment, and was encouraged to learn new motor skills, and to practice out of therapy sessions. It is not stated how this encouragement was standardised between subjects; although subjective reports from patients and therapists suggested that the patients in the enhanced therapy group did carry out more exercise out of therapy sessions. Subjects were assessed using a "motricity index". Results demonstrated that the enhanced therapy group had greater recovery in arm mobility than the conventional therapy group during the first month ($p=0.02$). However this difference was not continued after the first month (from 1-6 months, $p>0.02$). No difference in functional ability, as assessed by the Barthel Index was found at any time during the study. The standardisation of the treatment interventions given in this study must be questioned. The authors identified that the subjects in the enhanced therapy group received more than double the amount of treatment for the arm than did the conventional therapy group. This means that any differences in outcome cannot legitimately be attributed to the type of treatment, but only to the amount of treatment. Sunderland et al (1992) acknowledged this limitation and identified that questions regarding the "precise locus of treatment effect" could not be answered. A follow up study of 73% of the patients in the trial by Sunderland et al (1992) revealed that the differences in outcome between the enhanced therapy group and conventional therapy group were not sustained after 1 year (Sunderland et al, 1994). The authors concluded that the enhanced therapy group reached a "plateau" in recovery faster than the conventional therapy group. The lack of differences after 1 year was therefore due to some late improvement in the conventional therapy group and no improvement in the enhanced therapy group (Sunderland et al, 1994). Thus this study implies that the enhanced treatment did not influence long-term recovery from stroke.

Brunham and Snow (1992) carried out a single-subject design that aimed to compare NDT with conventional treatment. NDT was defined as "specific handling techniques performed by the physiotherapist aimed at inhibiting abnormal movement and tone and facilitating normal postural tone and movement." Conventional treatment was defined as "a combination of several treatment approaches commonly used by therapists who are not NDT-certified but are experienced in working with neurological conditions". Despite the definition of conventional treatment referring to treatment by therapists without NDT certificates, for this study the same therapist carried out both the NDT and the conventional treatment. For the 3 subjects, who had various neurological deficits, a problem was identified and a target treatment goal set. 15 minutes per day were spent treating the identified problem, with the treatment approach assigned using blocked randomisation. The patient outcome was assessed and scored from videography on each of the 10 treatment days. The authors suggested that the results demonstrated that the conventional treatment was more beneficial than NDT. However, this study had several limitations, such as the ordering of treatments, the effects of the daily randomisation, the effects of the other treatment that the subjects were receiving, the subjectivity of the goal setting and outcome measurement, and bias associated with the use of only one therapist to apply two treatment approaches. This study therefore adds little to the debate concerning the efficacy of different treatments, although it emphasises the need for well-designed studies.

Richards et al (1993) addressed questions relating to the amount and the type of treatment administered to patients with infarcts within the middle cerebral artery. 27 patients were randomly assigned (using a blocked method, stratified according to Barthel scores) to one of three treatment groups. The experimental group received an "intensive focussed approach" which was specifically aimed to improve gait. The authors stated that the treatment included the use of tilt tables, limb load monitor, resisted exercise and the treadmill. Control group 'A' received treatment of the same intensity as the experimental group, but comprising a "traditional" approach based on "neurophysiological techniques and practice". Control group 'B' received the same type of treatment as group 'A', but at a lower intensity. Motor performance and function were assessed by an independent assessor after 6 weeks, 3 months and 6 months, using a number of standardised tests (Fugl Myer, Barthel, Berg balance scale, gait evaluation). No significant difference was found between any of the measured parameters, with the exception of gait velocity that was significantly different in the experimental group than in either of the control groups, for the 6-week assessment ($p<0.05$). The authors concluded that the difference between the types of therapy was more important than the difference between the time of therapy. The ability to draw firm conclusions from this study, which identified a significant difference in only one parameter, and which was not sustained after the first assessment, must be challenged. The authors identified that a larger study would be required before these results could be used to influence the treatment of patients.

A prospective randomised study was carried out by Gelber et al (1995) to compare 'neurodevelopmental treatment (NDT)' with 'traditional functional retraining (TFR)'. 27 patients who had developed hemiplegia less than 1 month prior to entry into the study were randomised into either a NDT or TFR group. Poor descriptions and a lack of literature cited regarding the treatments administered are provided by the authors; the NDT approach appears to be based on the treatment advocated by the early texts of Bobath (1970). The TFR is described as practising functional tasks even in the presence of spasticity or abnormal postures (Gelber et al, 1995). A series of assessments (functional and / or motor) were carried out at admission, discharge, 6 months after discharge, and 12 months after discharge. The results demonstrated that there were no significant differences ($p<0.05$) between the two treatment groups for any of the assessments at any of the assessment times, with the exception of the gait velocity at the time of discharge which was significantly higher in the NDT than the TFR group ($p=0.04$). The difference in gait velocity was not maintained during follow-up tests. The authors stated that the therapists involved in administering treatment to the patients had received strict guidelines for treatment; however, the failure of the authors to provide clarification regarding the precise nature and supporting literature for the two treatment approaches limits the ability to draw generalised conclusions from this study. The knowledge of the assessors regarding the treatment group of the patient may have resulted in bias. In addition, the authors did not address issues related to the presence of patients on the same ward, carrying out different practice of tasks, as patients assigned to the alternative treatment group. The assistance of the nursing staff in any practice of tasks carried out on the ward may have also influenced the results. This study illustrates the necessity of defining variables and identifying a suitable methodology in order to carry out a comparison of different treatment approaches.

These studies have demonstrated some of the difficulties relating to the comparison of the efficacy of different types of physiotherapy for patients with stroke. In addition to problems related to the identification of the population and sample, and the variation within the sample; the identification of reliable, valid and sensitive assessments of outcome; the avoidance of tester bias; and problems with study designs, it can be difficult to ensure that the type of treatment administered is consistent. This is made difficult through the use of inconsistent terminology; for example the use of the terms "traditional" and "conventional" to describe different, often poorly defined, treatment approaches (Stern et al, 1970; Logigian et al, 1983; Dickstein et al, 1986; Basmajian et al, 1987; Lord and Hall, 1990; Brunham and Snow, 1992; Sunderland et al, 1992). The difficulty is increased through the lack of details surrounding the practical element of many of these approaches. For example, although Basmajian et al (1987) stated that the Bobath treatment was as explained in the Bobath text (Bobath, 1978), Bobath treatment is not prescriptive and treatment depends on the nature of the patients deficits. It is consequently impossible to know whether the treatment being administered is either consistent between patients or between physiotherapists, or whether it is consistent with the treatment approach described. Problems specifically related to the investigation of the Bobath approach are associated with changes that have occurred within the approach over a number of years. The techniques and theories proposed in some texts (e.g. Bobath, 1978) are not synonymous with the techniques and theories described in other texts (e.g. Davies, 1985); yet the approach maintains the same name. Wagenaar et al (1990) described the neurodevelopmental approach to treatment as a modernised version of the Bobath approach. However, which parts of the original Bobath approach have changed and which remain is unclear. In order to allow systematic evaluation of physiotherapy techniques, the accepted theories and practice of each of the specific treatment approaches must be clearly defined and published in an available format.

In a novel paper, Lettinga et al (1997) carried out a qualitative comparison of the Bobath and the Brunnström approaches based on an analysis of the content of the available texts describing these approaches. Using a methodology based on discourse analysis, Lettinga et al (1997) compared the treatments advocated in texts supporting the Brunnström approach (Brunnström, 1970, and Sawner and LaVigne, 1992) with the texts supporting the Bobath concept (Bobath, 1970, 1978, 1990 and Davies, 1985, 1990). The authors carried out a systematic analysis of the biomedical vocabularies and psychosocial terminology, and the interventions and routines described in the texts (Lettinga et al, 1997). The authors acknowledged that the texts in support of the different approaches may themselves differ and stated that, where there was differences between the Bobath (1978, 1990) texts and the Davies (1985, 1990) texts, the approach described in the Davies texts was followed. The authors concluded that the described approaches were very different, despite the fact that both approaches base their treatments on neurological principles. The authors identified that whereas the Brunnström approach acknowledged the effect of a patient's motivation, Bobath therapists did not address issues of motivation. In contrast, Lettinga et al (1997) proposed that the Brunnström approach was not concerned with a patient's perspective, psyche or social environment, while this was central to the Bobath approach. While this novel approach to the comparison of treatment approaches contrasts enormously with the quantitative research approach previously adopted in the comparison of approaches, it does identify several fundamental and theoretical differences between the approaches. While this qualitative methodology cannot assist directly in the identification of the efficacy of treatment approaches, discourse analysis may potentially be useful in the identification of theoretical differences, similarities and contrasts between approaches. However, the lack of available up-to-date written descriptions of approaches, such as the Bobath concept, will reduce the legitimacy of carrying out qualitative analysis based on written material.

The clearly defined parameters of the Motor Learning approach, which is based on available scientific literature, and the assumption that individuals with neurological damage will learn in the same manner as healthy subjects, provide a basis on which controlled trials can be carried out. Dean and Shepherd (1997) carried out a study that aimed to investigate the efficacy of a training program based on the Motor Learning approach as compared to a control intervention. 20 subjects, who had suffered a stroke less than 12 months previously, were randomly assigned to an experimental or a control group. Subjects in both groups were given 10 training sessions in their own homes by one of the researchers, over a 2-week period. The experimental group carried out a training program that was designed to improve their sitting balance. This training comprised a series of reaching tasks, with the researcher systematically varying the conditions. The control group carried out a series of cognitive-manipulative tasks that involved reaching over very small distance (less than 50% of arm length). All subjects were tested before and after the training period. The tests comprised 2 seated reaching tasks and an assessment of rising to stand (with ground reaction forces, GRF, under the feet being recorded for both of these tasks), and a number of walking and cognitive tasks. The assessor was blind to the group that the subject had been in. The results demonstrated that the subjects in the experimental group performed significantly better than the control group for the reaching tasks at the post test ($p<0.01$ for the distance reached; $p<0.01$ for peak GRF under affected leg). The experimental groups improved from the pre-test to the post-test ($p<0.01$) for reaching, while the control group did not. In addition the experimental group had a significant increase in the peak GRF through the affected leg during rising to stand between the pre- and post-test ($p=0.02$). There was no significant difference in the ability to rise to stand for the control group ($p=0.247$). No differences were found in walking ability; some differences were found for letter cancellation cognitive tasks ($p=0.002$) (Dean and Shepherd, 1997). The authors concluded that this study supported the Motor Learning approach to the rehabilitation of patients with stroke. Although these study results initially appear to lend substantial evidence for the ability of patients to improve their functional ability through training based on the Motor Learning approach; caution should be taken in interpretation of the study. The study was carried out on a small sample of subjects, who were all members of a similar population; this limits the ability to generalise the results of this study. The training was carried out by one therapist, who was one of the researchers. The relationship between the researcher and the patients, and the researcher's own beliefs in the training programs may have resulted in substantial bias in the outcome. In addition, this study must be criticised for not carrying out a follow-up test of retention. The motor learning literature emphasises that learning, or permanent effects of training, can only be assessed through follow-up tests of retention (Schmidt, 1991; Magill, 1993). Dean and Shepherd (1997) have only carried out one post-test and, although the period of time between the end of training and the test is not made explicit, this test could be argued to reflect the performance immediately after the practice sessions and not the degree of permanent change in performance.

While the majority of studies of treatment aimed at functional recovery following neurological damage have investigated the efficacy of treatment techniques which have previously been advocated for clinical use by physiotherapists, Mauritz et al (1997) investigated the efficacy of a specially designed treatment approach. Mauritz et al (1997) identified that Hesse et al (1993, 1994) had investigated the effect of 4 weeks of intensive inpatient training, aimed at improving gait symmetry, with 148 patients (on average 130 days post stroke) and that no improvement in gait symmetry parameters occurred. The treatment given to the patients in this study was based on the Bobath concept. Mauritz et al (1997) hypothesised that the lack of improvement may have been directly linked to the treatment principles. Consequently Mauritz et al (1997) proposed that training should emphasise a more functional level of locomotion, and that this may be achieved through treadmill training. Seven patients with ischaemic infarcts in the territory of the middle cerebral artery were treated using an A-B-A single-case design. Each phase lasted for three weeks. During the A-phase treatment comprised of treadmill training. Initially the patient was partial weight-bearing, with a harness supporting 30% of body weight. This was reduced to 0% within 4-15 days. Therapists worked with the patient to achieve a normal pattern of gait. During the B-phase treatment was based on the Bobath concept. Parameters of gait and functional ambulation ability were assessed once a week throughout the trial. The results demonstrated a weekly improvement in gait symmetry and functional ambulation during the A phases, with no change in outcome during the B phase. Despite a lack of information pertaining to the subjects of the study, the treatment interventions, and the results obtained for different subjects; and the potential effects of bias from the treating physiotherapists; the results of this study appear to demonstrate that the new treatment approach led to better functional outcome than the well-established Bobath approach. These results suggest that the physiological basis and treatment techniques advocated by the Bobath approach, which is the most commonly used approach by physiotherapists (Nilsson and Nordholm, 1992; Carr et al, 1994), may not result in optimal functional outcome. The beneficial effects of the treadmill training intervention could be hypothesised to lend support to the Motor Learning approach, which advocates repetitive training of motor tasks. This study appears to be the first to demonstrate that one treatment approach is more beneficial than another is. However, the failure by the authors to relate the "new" treatment to existing theories of recovery and re-learning, limits the ability to generalise from the results. Further research, with larger sample sizes and more clearly defined parameters, is required to investigate the findings of this study.

5.4.3 Summary and Conclusions

In conclusion, although there is evidence that physiotherapy is more beneficial than natural recovery alone (Smith et al, 1981), there is little evidence that any one type of treatment is more beneficial to recovery than others (Stern et al, 1970; Logigian et al, 1983; Dickstein et al, 1986; Lord and Hall, 1986; Basmajian et al, 1987; Wagenaar et al, 1990; Gelber et al, 1995). This is supported by Ernst et al (1990) who, following a review of physiotherapy treatment for patients with stroke, concluded that "existing data suggest that if an optimal physical therapy exists, it has not yet been identified". Controlled clinical trials of physiotherapy interventions are essential if an optimal approach to treatment for stroke patients is to be identified. At present the ability to carry out controlled trials of different treatment approaches is limited by the poor documentation relating to some of the approaches (Ashburn, 1995). This has been illustrated to be the situation regarding the Bobath approach (Lennon, 1996). The Motor Learning approach is based on scientific theories and subsequently generates the production of testable hypotheses (Carr and Shepherd, 1987, 1989, 1990).

Although there are some fundamental differences between the treatment approaches which have been advocated over the years, common to all of the approaches is the aim to improve functional ability and to achieve more normal posture and movement (Partridge, 1996). Partridge (1996) also identified that there were other similarities between the different treatment approaches, with many of the approaches citing similar references, evidence and techniques. A further commonality between the different treatments is the lack of scientific evidence in support of the approaches (Ashburn, 1995; Partridge, 1996).

Ashburn (1995) identified that the treatments used in the clinical setting may not now follow the approaches that are advocated in the literature:-

> "The pioneers and their immediate disciples were the purists in following treatment principles, but in recent years modifications have been made to programmes and greater flexibility has been suggested (Kidd et al, 1992, Connolly and Montgomery, 1991). It is therefore misleading to believe that most physiotherapists will follow an approach in a uniform or purist manner. Most clinicians are selective and adapt techniques and procedures according to their clinical expertise and knowledge of skills, although they are most likely to favour and support one approach."

This statement is supported by the findings of Nilsson and Nordholm (1992) and Carr et al (1994), which demonstrated that clinicians place more value on their clinical experience than on the available literature. Good (1994) also concurred that therapists integrate components from different approaches into their treatments. In this manner, physiotherapy for patients with neurological deficits will continue to be adapted and updated through inductive processes. Rather than the perpetual cycle of attempting to develop theories based on scientific evidence in order to explain clinical observations, there is a necessity to identify and evaluate the currently used approaches and base the practical approaches on sound scientific research.

6. Rationale for study

6.1 Overview

Stroke can cause severe disability and can lead to an inability to carry out daily functional activities. The rehabilitation of patients following stroke causes a significant burden on health care resources. A common problem following stroke is the inability to maintain or obtain balance during functional activities (Ashburn, 1997). Balance has been identified to be a multifactorial concept, which cannot be assessed using any one parameter (Berg, 1989; Winter et al, 1990). Assessment of the symmetry of weight distribution during the maintenance of postures and during movement has been proposed to be an appropriate method for the assessment of aspects of balance in patients with stroke (e.g. Murray and Peterson, 1973; Bohannon and Larkin, 1985; Sackley and Lincoln, 1991; Nichols et al, 1995). Following stroke, patients have problems specifically related to the ability to achieve symmetrical weight distribution during sitting (Carr and Shepherd, 1989a; Bobath, 1990), standing (e.g. Bohannon and Waldron, 1991; Sackley, 1991) and rising to stand and sitting down (e.g. Engardt and Olsson, 1992; Durward, 1994). In addition, patients with stroke have problems of movement relating to the control of the COP within the BOS during weight-shifting activities such as reaching (e.g. Murray et al, 1975; Dettman et al, 1987; Bullock-Saxton et al, 1991).

Assessments of symmetry of weight distribution and weight-shifting must be executed using objective measurement systems which have been demonstrated to provide valid and reliable results. Such a system has been developed at Queen Margaret College, Edinburgh (Durward, 1994). Durward (1994) has used this system to assess the symmetry of weight distribution during rising to stand, standing and sitting down. This system has the potential to be adapted to allow the objective measurement of the symmetry of weight distribution during sitting, and the assessment of the ability to transfer weight in sitting. This system is therefore suitable for the objective assessment of the symmetry of weight distribution during sitting, standing, rising to stand and sitting down, and the ability to transfer weight during reaching out to the side from a sitting position. The ability to quantify these parameters accurately provides a novel and valuable ability to assess the recovery of patients with stroke during rehabilitation, and to compare aspects of balance in stroke patients with the balance ability of healthy subjects.

There are several different treatment approaches advocated for the rehabilitation for patients with stroke. At present there is no experimental evidence to indicate that any one treatment is more beneficial to another (Ernst, 1990; Ashburn, 1995; Partridge, 1996). The majority of the treatment approaches are based on neurophysiological evidence (Ashburn, 1995). The Bobath approach, based on theories of neuroplasticity, is the most commonly used physiotherapy approach for the treatment of patients with stroke (Nilsson and Nordholm, 1991; Carr et al, 1993; Lennon, 1996; Sackley and Lincoln, 1996). Scientific evaluation of the Bobath concept is limited due to the lack of available written material (Lennon, 1996). Although used less than the Bobath approach, use of the Motor Learning approach has increased since the 1980s (Nilsson and Nordholm, 1991; Carr et al, 1993). The Motor Learning approach is based on scientific evidence from a number of different disciplines (Carr and Shepherd, 1987, 1989a, 1992). The Motor Learning approach is based on the assumption that individuals with neurological damage following stroke will relearn functional activities in the same manner as a healthy individual will learn a new motor skill (Carr and Shepherd, 1987, 1989a, 1992). Evidence relating to motor learning in healthy subjects demonstrates that skills are learnt through practice and repetition of the skill under varied conditions, with the provision of appropriate feedback (Schmidt, 1991; Magill, 1993). The evidence pertaining to optimal practice and feedback conditions has been obtained through neuropsychological orientated research. However, there is substantial neurophysiological evidence to suggest that practice of a motor task can effect long term plastic changes within the central nervous system (Kandel and Schwartz, 1985; Gilman and Newman, 1992; Dobkin, 1993; Nolte, 1993; Lee and van Donkelaar, 1995; Bear et al, 1996; Rosenzweig and Bennett, 1996; Seitz and Freund, 1997). It has been proposed that the neurophysiological processes of motor learning are similar to the process of recovery following neurological damage (Dobkin, 1993; Devor, 1994; Lee and van Donkelaar, 1995; Rosenzweig and Bennett, 1996; Seitz and Freund, 1997). This therefore supports the proposal by Carr and Shepherd (1987, 1989a, 1992) that functional activities lost following stroke can be recovered through practice and repetition, using training regimes based on the evidence for the optimal learning of new motor skills.

6.2 *Research aims*

6.2.1 General research aims

The aim of this study was to investigate the ability of patients with stroke to regain a functional activity through the practice of that activity, when the practice was based on the evidence for optimal motor learning. Following stroke, many patients have problems with aspects of balance during the maintenance of postures and during movement. Problems include an inability to maintain symmetrical weight distribution during sitting, standing, rising to stand and sitting down, and an inability to weight-shift during sitting. The aim of this study was therefore to assess the ability of patients with stroke to perform these functions, and to investigate the effect of practice on the functional ability. Since it has been suggested that training in sitting balance, using reaching to encourage weight transference, may result in improvements in the ability to perform rising to stand with symmetrical weight distribution (Dean and Shepherd, 1997) the aim of this study was to implement a training regime aimed at improving balance in sitting. The evidence pertaining to specificity and transference of training fails to prove whether the training of a task such as sitting will result in changes in associated tasks. Assessments of the symmetry of weight distribution during standing, rising to stand and sitting down, and a validated functional index (the Barthel Index) in addition to assessments directly relating to balance in sitting will allow questions regarding specificity and transference of training to be addressed. The motor learning literature emphasises the importance of tests of retention in order to assess the permanent learning effect of a training regime: it is therefore essential to include follow-up assessments of outcome, in addition to assessments of performance during the period of training.

6.2.2 Specific research aims

- To investigate the pattern of recovery of symmetry of weight distribution during sitting, standing, rising to stand and sitting down, and the ability to transfer weight during reaching out to the side from a sitting position, in patients with recently acquired stroke.
- To investigate the effect of a programme aimed at improving sitting balance, comprising of practice sessions based on the evidence for the optimal acquisition of new motor skills (as advocated by the Motor Learning approach), in patients with recently acquired stroke.

6.3 Research Objectives

1) To confirm the validity and reliability of the measurement system developed by Durward (1994) for use in the objective assessment of symmetry of weight distribution during sitting, standing, rising to stand and sitting down, and weight transference during reaching out to the side from a sitting position.

2) To use the measurement system developed by Durward (1994) to obtain normal data sets for the measurement of symmetry of weight distribution during sitting, standing, rising to stand and sitting down, and weight transference during reaching out to the side from a sitting position from a sample of young healthy subjects and a sample of elderly healthy subjects.

3) To develop a regime of practice aimed at the restoration of symmetry of sitting and the improvement of the ability to control weight shifting during sitting, based on the literature pertaining to the Motor Learning approach.

4) To conduct a randomised trial to investigate the recovery of symmetry of weight distribution during sitting, standing, rising to stand and sitting down, and weight transference during reaching out to the side from a sitting position in a group of patients with recently acquired stroke receiving standard physiotherapy (based on the

Bobath concept), and a group of patients with recently acquired stroke receiving standard physiotherapy plus an additional regime of practice (based on the Motor Learning approach).

5) To investigate the profile of recovery of symmetry of weight distribution during sitting, standing, rising to stand and sitting down, and weight transference during reaching out to the side from a sitting position in the two groups and hence determine the effect of practice sessions based on the literature pertaining to the optimal acquisition of new motor skills (as advocated by the Motor Learning approach).

6) To discuss, based on the data collected, methods of assessment of functional ability for patients with stroke, and to comment on disability and recovery following stroke and during in-patient rehabilitation.

6.4 Hypotheses

6.4.1 Healthy Subjects

A. Young and elderly healthy subjects demonstrate symmetrical weight distribution during sitting, standing, rising to stand, and sitting down.

B. Young and elderly healthy subjects demonstrate a consistent pattern of weight transference during reaching out to the side from a sitting position.

C. There is no relationship between the age, weight, height or gender of the subjects and the objective measurements of symmetry of weight distribution during sitting, standing, rising to stand, and sitting down, and weight transference during reaching out to the side from a sitting position.

6.4.2 Subjects with recently acquired stroke

D. The symmetry of weight distribution during sitting, standing, rising to stand, and sitting down, and the weight transference during reaching out to the side from a sitting position, of subjects with recently acquired stroke is different from that of young and elderly healthy subjects.

E. The symmetry of weight distribution during sitting, standing, rising to stand, and sitting down, and the weight transference during reaching out to the side from a sitting position, of subjects with recently acquired stroke will become more similar to that of young and elderly healthy subjects, over a period of 7 weeks during which standard physiotherapy (based on the Bobath concept) is administered.

F. There are relationships between the symmetry of weight distribution during sitting, standing, rising to stand, and sitting down, and the weight transference during reaching out to the side from a sitting position in individual patients with recently acquired stroke.

G. There is a relationship between the functional recovery, as assessed using the Barthel index, of patients with recently acquired stroke and the symmetry of weight distribution during sitting, standing, rising to stand, and sitting down, and the weight transference during reaching out to the side from a sitting position

6.4.3 Effect of regime of practice aimed at improving sitting balance

H. Patients with recently acquired stroke receiving standard physiotherapy (based on the Bobath concept) plus an additional regime of practice (based on the Motor Learning approach) aimed at improving sitting balance have greater recovery of symmetry of weight distribution during sitting, standing, rising to stand and sitting down, and weight transference during reaching out to the side from a sitting position than patients with recently acquired stroke receiving standard physiotherapy (based on the Bobath concept).

I. The difference in recovery of the symmetry of weight distribution during sitting, standing, rising to stand and sitting down, and weight transference during reaching out to the side from a sitting position, between patients with recently acquired stroke receiving standard physiotherapy (based on the Bobath concept) plus an additional regime of practice (based on the Motor Learning approach) and patients with recently acquired stroke receiving standard physiotherapy (based on the Bobath concept) is maintained during tests of retention for up to 2 weeks following the cessation of the additional regime of practice.

7. Experimental design

In order to meet the study aims and objectives and to test the formulated hypotheses, objective measurements of posture and movement were collected from healthy subjects, and a randomised controlled trial was carried out to investigate the effects of independent practice in patients with recently acquired stroke. This chapter outlines the experimental design of the randomised controlled trial, and identifies the populations and samples included in the study. The subsequent chapters describe the measurement system (chapter 8) and details of the methodology, including the testing protocol and design of the regime of independent practice (chapter 9).

7.1 Randomised controlled trial

A blocked randomised controlled design was selected to test the effectiveness of the independent practice regime. Patients meeting the inclusion criteria were randomly assigned, using blocked randomisation techniques, to either the Normal Physiotherapy Group or to the Practice Regime Group. The maximum number of practice group subjects that could attend the practice session on any one day was limited due to the available resources. Thus, in order to increase the power of the study, and to include a maximum number of patients in the study, the patients were assigned to the normal treatment and practice regime groups with a ratio of 2:1. Immediately after consent and randomisation all subjects had a series of baseline measurements of balance (as outlined in the testing protocol). Thereafter all subjects had the testing procedure repeated weekly for a further 6 weeks (or until the subject was discharged home or a medical problem intervened). Subjects in the practice regime group attended training sessions on 5 days per week, commencing on the day after the baseline measurements of balance and continuing for 4 weeks. During these training sessions the developed practice regime (see section 9.2) was followed. All subjects continued to attend for their standard physiotherapy treatment, which was based on the Bobath approach. If patients were discharged from hospital they were also discharged from the clinical trial. The design of the randomised trial is illustrated in Figure 7.1.

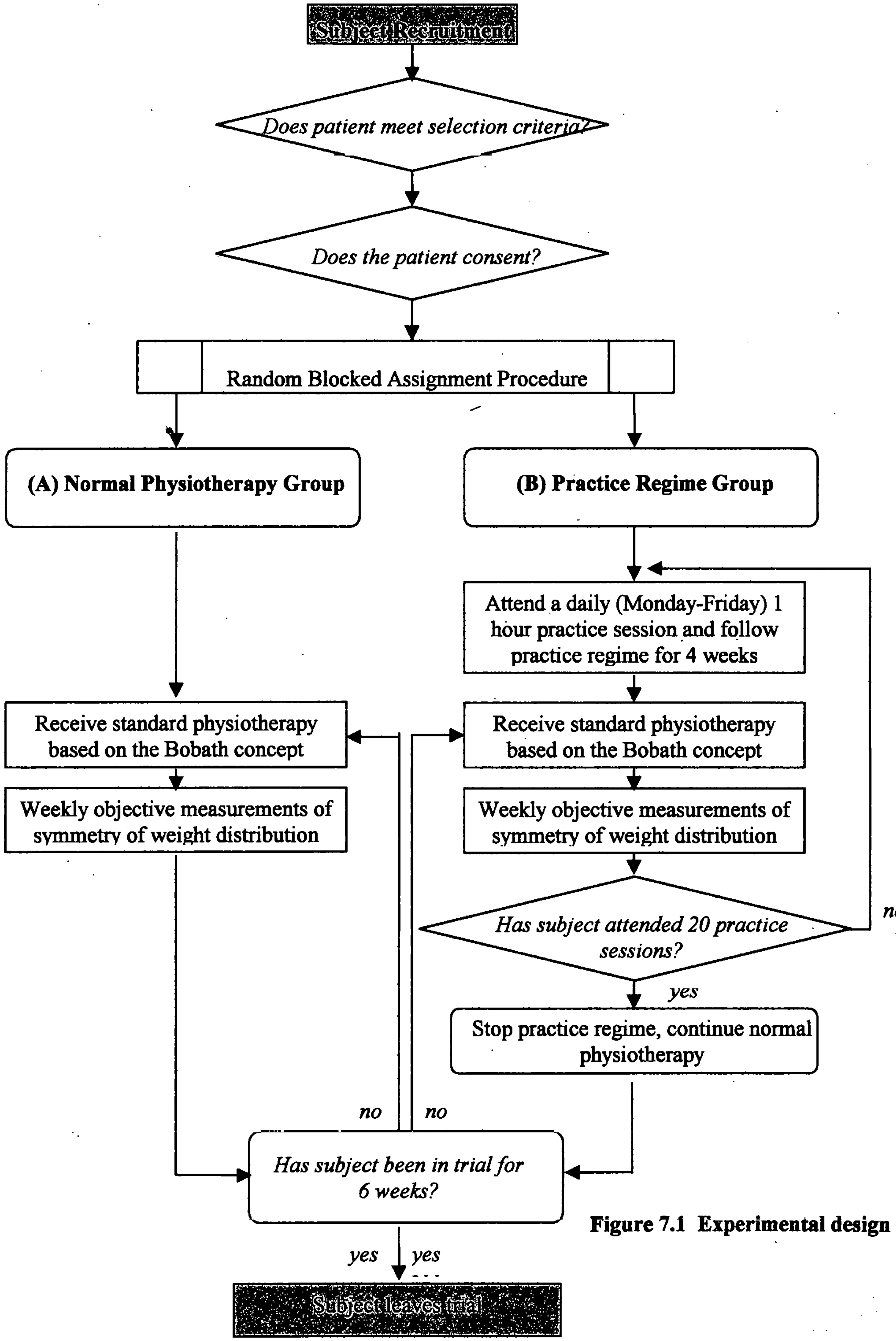


Figure 7.1 Experimental design

In addition to the objective measurements of balance the following information was recorded:-

- Personal details - age, sex, side of hemiplegia, nature and classification of stroke (Bamford et al, 1991), past medical history, factors relating to their present admission etc. - gathered from the patients' notes.
- Validated functional scores (Barthel Index and rising to stand section of Motor Assessment Scale) - recorded weekly by the nursing and physiotherapy staff.
- The number and length of time of physiotherapy treatments - gathered from the statistical information recorded by the physiotherapists.

7.2 Healthy subject population and sample

- 20 volunteers from each of the following populations were tested:-
  (i) Healthy students aged 18-30 years, at Queen Margaret College, Edinburgh. This was a similar age group to that used in many studies of symmetry of stance.
  (ii)Healthy subjects aged over 60 years who were members of an "over 50's" exercise group held at the physiotherapy department of the Western General Hospital, Edinburgh. This group was similar in age to the hemiplegic subjects included in the clinical trial.

- The subjects tested comprised a sample of convenience, recruited after being asked to volunteer to take part in the study.

- Exclusion criteria included any known musculoskeletal, neurological, or vestibular deficits and the consumption of alcohol within 24 hours prior to testing.

- Ethical approval was granted from the Queen Margaret College Ethics Committee and the Lothian 'Healthy Subjects' Ethics Sub-Committee. All subjects were requested to read an information sheet and sign a consent form (see Appendix G) prior to inclusion in the study.

7.3 Patient population and sample

The literature did not indicate if particular criteria were necessary for patients to undertake independent practice. No similar research was available to suggest which patients might benefit, and which patients might not benefit from undertaking independent practice. There was no literature available that indicated which, if any, neurological deficits contraindicated independent practice. Hence the following inclusion criteria were applied:-

- In-patient at the Western General Hospital, Edinburgh, with diagnosed stroke, admitted during 1997.
- Attending regular physiotherapy sessions at the physiotherapy gym.
- Cerebrovascular accident, as diagnosed by the medical staff at the Western General Hospital, within 6 weeks prior to inclusion.
- Able to understand the nature of the study and give informed consent.
- Achieved one minute of sitting balance, as assessed by the patient's physiotherapist.
- Not yet achieved 10 independent steps, as assessed by the patient's physiotherapist.
- No known disabilities, pathology, or neurological deficit which affected mobility, prior to the current hospital admission.

A written sheet was given to all subjects detailing the nature of the trial and the process involved (Appendix H). Further verbal clarification was offered, to the patients or their relatives, and an independent medical practitioner was also available for advice. Three days later, written consent (or witnessed consent if patients were unable to write) was requested from each subject (Appendix H). The consent form stated:

- that they understood the nature of the trial and consented to participating as a subject;
- that they could withdraw from the trial at any stage without penalty or disapproval;
- that they might be withdrawn from the trial at any stage by the researcher, senior physiotherapist or medical consultant from the Stroke Unit at the Western General Hospital.

- that should any potential medical problems be observed during the study, these would be reported to the medical or nursing staff on the Stroke Unit.

During the 10 months in which subjects were recruited (February 1997 until November 1997) 33 patients met the inclusion criteria. Of these 33 patients, 5 refused to take part in the study, leaving a total of 28 patients who were recruited into the study. The inclusion criteria resulted in the exclusion of patients with receptive communication problems: this resulted in the recruitment of fewer subjects with right hemiplegia than subjects with left hemiplegia (17 left / 11 right). The inclusion criteria excluded a number of patients with strokes classified as TACI, as one minute of sitting balance was not achieved within 6 weeks of the cerebrovascular accident. Many patients with milder strokes were also excluded, as they were able to perform 10 independent steps on the first physiotherapy assessment within the physiotherapy gym. Additionally a number of patients were excluded due to previous disabilities resulting in impaired mobility. This group included patients with amputations, visual impairment, mental impairment and other neurological disorders.

Ethical approval was granted for this study by the Lothian Medical Ethics Committee.

8. Measurement System

8.1 *Description of the measurement system*

8.1.1 Overview of the measurement system

The measurement system was designed at Queen Margaret College, Edinburgh (Durward, 1994). The system comprised a standard chair with four-section force platforms, placed within the seat of the chair and under the feet, which were each capable of measuring vertical forces. The armrests of the chair were modified to enable the measurement of vertical forces delivered by the hands and arms. A switch attached to the backrest served to identify whether a force was applied against the backrest. Thus this system measured vertical forces from ischial, thigh, heel, forefoot and arm sections on the left and right sides. Additionally there was a remote hand-held switch for operator-controlled event marking.

Each of the 10 force measuring sections were attached through wires to a bank of strain gauged amplifiers. The amplified outputs from the force measuring sections and the signals from the backrest and operator-controlled switches were converted to digital form using a multi-channel, 12 bit external analogue to digital converter. The resulting signals were interfaced to a computer terminal. The measurement system is illustrated in Figure 8.1 - Figure 8.4. Details of the force measuring sections and electronic equipment are provided in Appendix B.

A standard upright chair (Figure 8.3) was used. The original seat was removed and a baseplate was mounted within the framework of the chair. Four force transducers were mounted on to the baseplate. Each of the 4 individual force-measuring sections was 0.19m wide and 0.17m long. These were positioned to be level with the anterior edge of the baseplate and centred within the lateral plane. The baseplate was 0.48m wide by 0.43m deep. A foam wedge was attached to the surface of each force measuring section. The foam was wedged shaped to prevent the foam sections touching one another when compressed. A vinyl upholstery cover was placed over the foam wedges and seat of the chair: this gave the chair a "normal" appearance, and provided a waterproof protection for the measurement sections. Figure 8.3 illustrates the seat with the foam wedges in place; Figure 8.4 illustrates the system without the foam wedges and Figure 8.2 illustrates the system with the upholstery cover on the seat.

The chair was mounted on a low platform (0.05m high). This prevented movement of the chair during human motion. Within the platform was a moveable carriage containing a baseplate on which was mounted four individual force measuring sections. These sections were identical to the sections within the seat of the chair. The moveable carriage allowed adjustment of the position of the foot measuring sections according to a subject's leg length and preferred foot placement. The carriage was secured on a running track by means of a sliding bolt that allowed fixation within 1cm increments. The running track remained in the centre of the width of the platform.

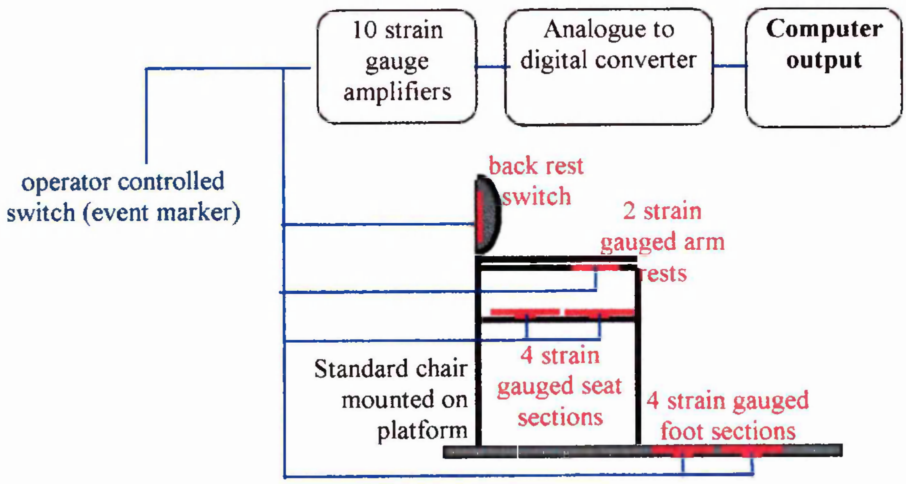


Figure 8.1 Schematic overview of the measurement system

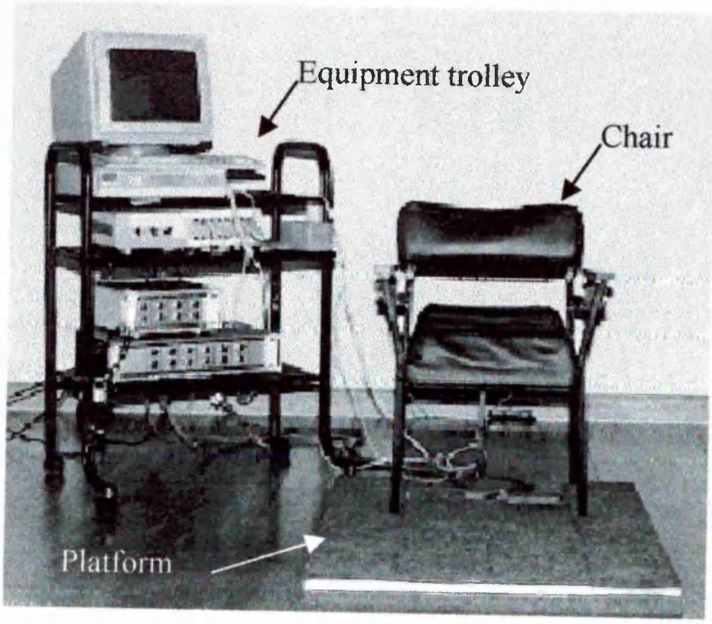


Figure 8.2 The measurement system

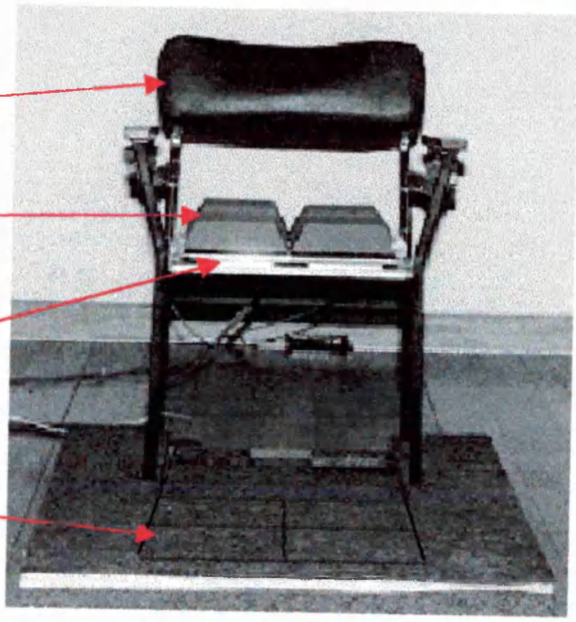


Figure 8.3 The chair and platform. Anterior view.

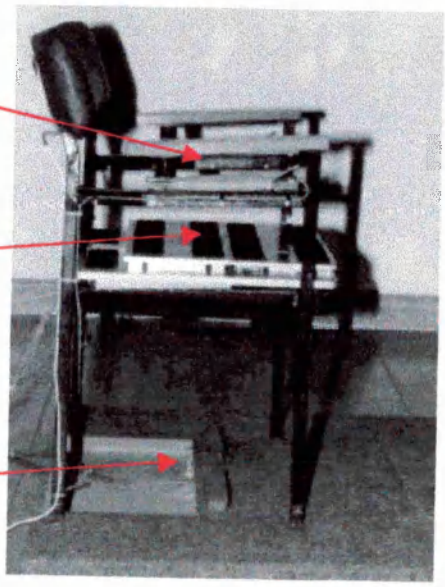


Figure 8.4 The chair and platform. Lateral view.

8.2 *System Calibration Checks*

8.2.1 Introduction

Accuracy refers to the systematic differences between the “reference” (true) and measured values. This can be considered as a systematic error (Allard et al, 1995). Precision refers to the repeatability with which a measured value can be obtained, and can be considered as a random error (Allard et al, 1995). In order to ensure that the measurement system was suitable for the proposed use it was necessary to identify the accuracy and precision of the system. In addition it was necessary to investigate the response of the system to directional and positional changes in application of force, and the effect of external factors on the system output.

8.2.2 Data Analysis

Data analysis was carried out by obtaining a number of statistical derivations from the recorded output. These included calculations of the standard error of the estimate, residuals, mean, standard deviation, range and measures of agreement (percentage close agreement).

The standard error of the estimate is a statistic that reflects the accuracy of a regression equation. The standard error of the estimate represents the average deviation of the differences between the predicted values on the regression line and the measured values (assuming Gaussian distribution). Two standard errors of the estimate above and below the regression line include 95% of all systematic errors. The residual of a point is a measure of the difference between that individual measured point, and the predicted point on the regression line, along the y-axis. The maximum absolute residual therefore represents the maximum difference between any measured and predicted point. A low standard error of the estimate with a comparatively high maximum residual therefore suggests that there are a small number of measured points that differ from the predicted line. A standard error of the estimate with a comparatively similar maximum residual is suggestive of a similar trend throughout the measuring range. The lower the standard error of the estimate and the maximum residual the higher the degree of accuracy. The accuracy of the calibration of the measurement system can therefore be reflected using the standard error of the estimate and the maximum residual, in combination with the equation of the predicted line.

The degree of precision can be assessed using the standard deviation and the range of a repeated set of measurements. The standard deviation provides a measure of the average deviation of a measured value from the mean measured value. The range provides a measure of the maximum deviation that occurs between a repeated set of measurements (assuming Gaussian distribution). 95% of the measured values will fall within 2 standard deviations of the mean value. A low standard deviation with a comparatively high range therefore suggests that there are a number of outliers in the measured values. A standard deviation with a comparatively similar range is suggestive of few outlying points. The lower the standard deviation and the range the higher the degree of precision. When a series of data is collected continuously over a period of time, the differences between the repeated measures can be explored by observing the frequency distribution of the measured values. The agreement between a set of repeated measurements can be assessed by calculating the percentage close agreement (PCA). This statistic reports the maximum difference between repeated measures that would enclose a specified percentage of the repeated measurements. In this investigation, the PCA was determined for percentage agreements of 80%, 95% and 100%. The PCA assesses the agreement between each of the individual repeated measures, while the standard deviation assesses the difference between each measure and the mean. The precision of the calibration of the measurement system can therefore be reflected using the mean, standard deviation and range of the repeated measures, in combination with the use of frequency distribution tables or charts, and values of the PCA.

8.2.3 Accuracy and calibration

In order to check the accuracy of the output from each measurement section, data was recorded from each section during loading and unloading. Vertical forces of up to 800N were sequentially applied and removed from each of the foot and seat sections. This maximum force was selected as it represented more than the average weight of a typical male. Vertical forces of up to 200N were sequentially applied and removed from each of the arm sections; this maximum force was selected as this represents more than the maximum recorded value of 22% of body weight placed through the arms by subjects with hemiplegia during rising to stand (Durward, 1994). Since Durward (1994) suggested that subjects with hemiplegia might apply an upward force on the arm section during rising to stand, it was also necessary to determine the accuracy of the response when an "upward" force is applied. A pulley system allowed loads of up to 100N to be sequentially applied and removed. The output from each section was recorded (Figure 8.5, Figure 8.6 and Figure 8.7), and the regression equations determined (Table 8.1). The regression equations and plotted lines illustrate that the response of the system to loading and unloading was linear and demonstrated no hysteresis. The mean gradient for all measurement sections was 4.10 computer units. 95% of the residuals around the mean regression line were within 0.40% of the applied load, suggesting a high degree of accuracy. For all further data recording the gradient of 4.10 computer units was therefore used to convert the data into units of force (newtons).

SECTION	LOADING	UNLOADING
LEFT HEEL	$Y = 4.10X + 386.7$	$Y = 4.10X + 388.0$
LEFT FOREFOOT	$Y = 4.09X + 387.1$	$Y = 4.09X + 387.6$
RIGHT FOREFOOT	$Y = 4.12X + 389.3$	$Y = 4.13X + 390.4$
RIGHT HEEL	$Y = 4.09X + 391.3$	$Y = 4.10X + 389.9$
LEFT ISCHIUM	$Y = 4.10X + 404.1$	$Y = 4.10X + 407.8$
LEFT THIGH	$Y = 4.09X + 404.3$	$Y = 4.09X + 409.8$
RIGHT THIGH	$Y = 4.08X + 402.5$	$Y = 4.09X + 400.1$
RIGHT ISCHIUM	$Y = 4.10X + 403.0$	$Y = 4.09X + 414.6$
RIGHT ARMREST	$Y = 4.10X + 400.8$	$Y = 4.09X + 402.1$
LEFT ARMREST	$Y = 4.09X + 401.2$	$Y = 4.10X + 401.3$

Table 8.1 Regression equations for loading and unloading of force sections

[X = force applied in newtons; Y = system output during application of force.]

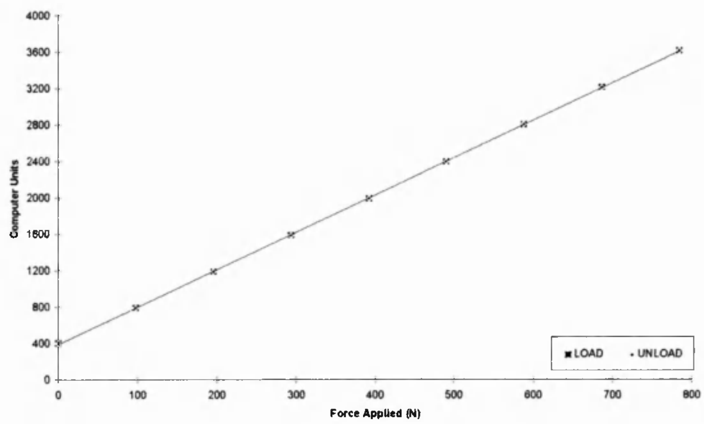


Figure 8.5 Regression lines derived from loading and unloading a foot section.

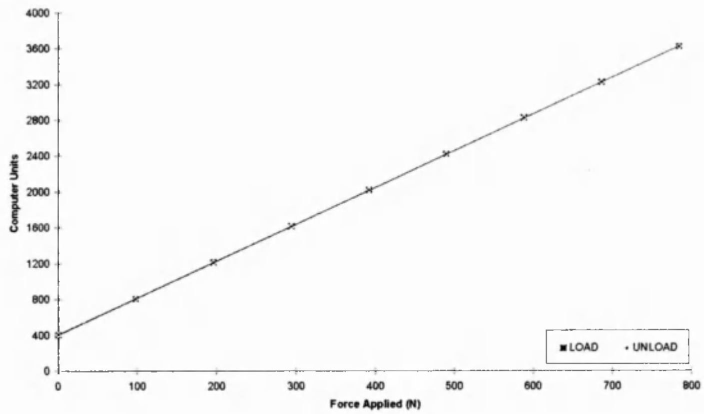


Figure 8.6 Regression lines derived from loading and unloading a seat section.

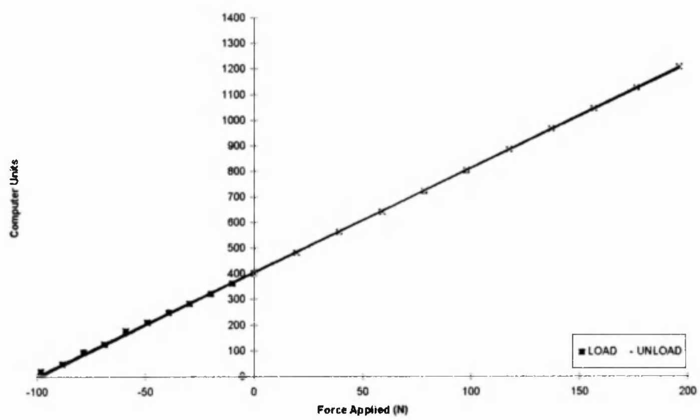


Figure 8.7 Regression lines derived from loading and unloading an armrest.

8.2.4 Precision and the effects of system noise

In order to identify the precision of the measuring system it was necessary to determine the effects of noise within the system on the computer output. The frequency of data collection most commonly used for studies of human performance is 50Hz. As this system was designed for the investigation of human performance, this was the frequency used in this experiment and in all subsequent experiments, unless otherwise stated. Two seconds of system output was recorded during the applications of loads of 0, 20, 40, 60 and 80kg on the four foot and four seat sections, and 0, 4, 8, 12, 16 and 20kg on the arm sections. Examples of the response and the noise at certain levels are given for a heel section (Figure 8.8 - Figure 8.10), a thigh section (Figure 8.11 - Figure 8.13) and an arm section (Figure 8.14 - Figure 8.16). The distribution of the noise was normal indicating that the system noise was random. The maximum standard deviation of system noise was approximately 1.0N (Table 8.2 and Table 8.3). Thus 95% of the measured output was within 2N of the mean recorded value.

mass	Left heel	Left forefoot	Right forefoot	Right heel	Left ischium	Left thigh	Right thigh	Right ischium
0kg	0.82	0.64	0.80	0.73	0.85	0.76	1.01	0.89
20kg	0.70	0.74	0.80	0.76	0.74	0.80	0.96	0.69
40kg	0.69	0.70	0.71	0.72	0.67	0.83	1.05	0.72
60kg	0.81	0.73	0.74	0.79	0.73	0.70	0.72	0.73
80kg	0.76	0.70	0.68	0.75	0.73	0.76	0.97	0.74

Table 8.2 Standard deviations of 2 seconds of output from foot and seat sections (N).

mass	Right arm	Left arm
0kg	0.62	0.55
4kg	0.54	0.54
8kg	0.49	0.49
12kg	0.51	0.43
16kg	0.55	0.44
20kg	0.53	0.53

Table 8.3 Standard deviations of 2 seconds of output from arm sections (N).

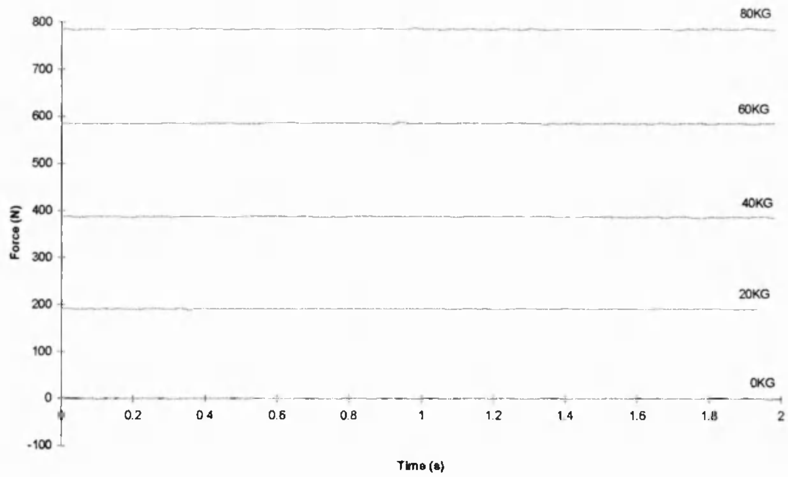


Figure 8.8 System output from foot section over 2 seconds during application of different loads.

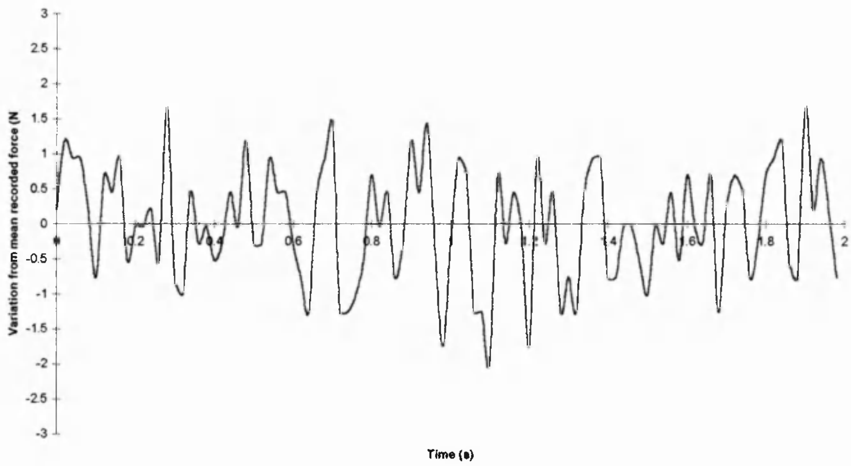


Figure 8.9 Variation in system output from foot section over 2 seconds – unloaded.

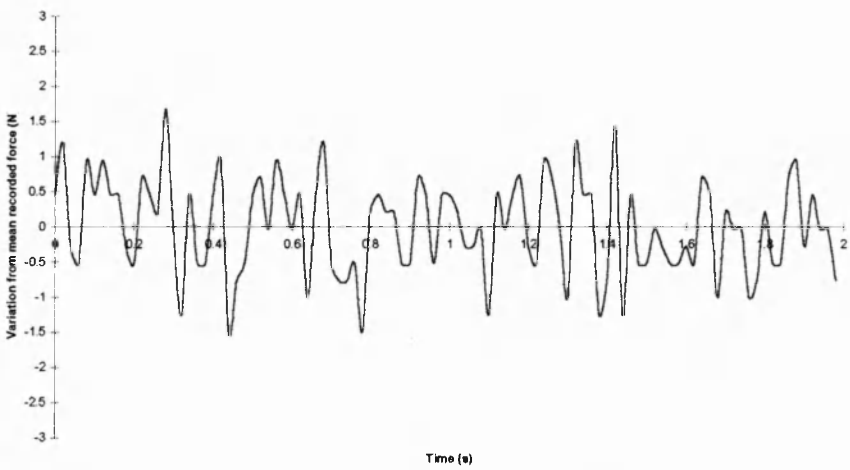


Figure 8.10 Variation in system output from foot section over 2 seconds –loaded with 40 kg.

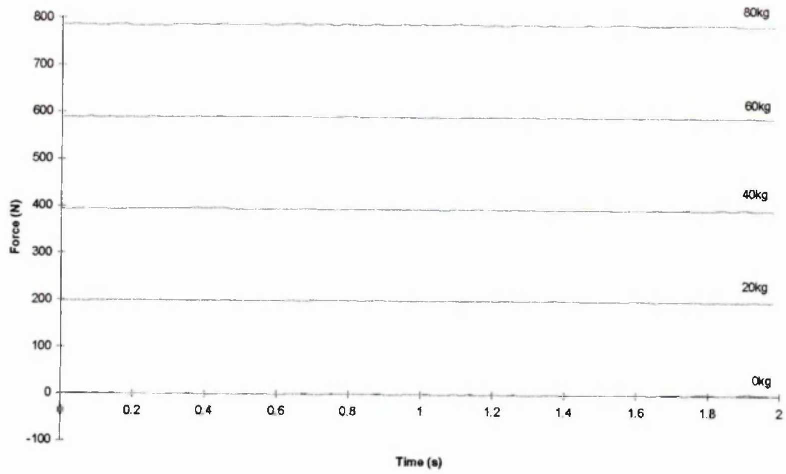


Figure 8.11 System output from seat section over 2 seconds during application of different loads.

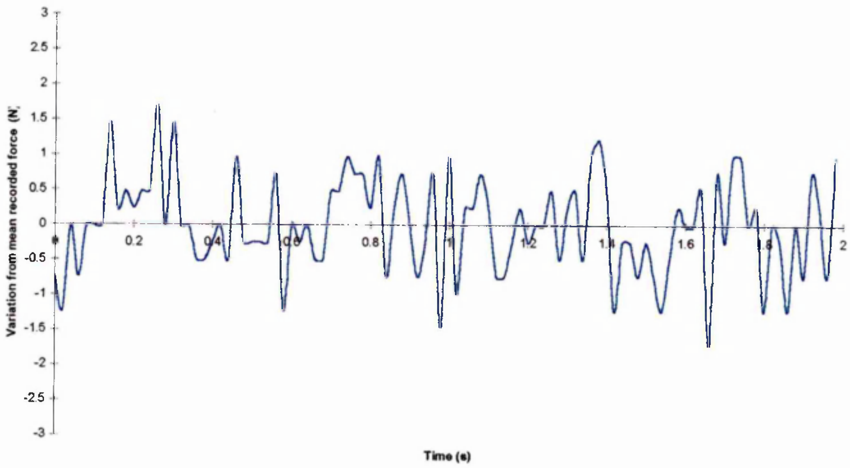


Figure 8.12 Variation in system output from seat section over 2 seconds – loaded with 20kg.

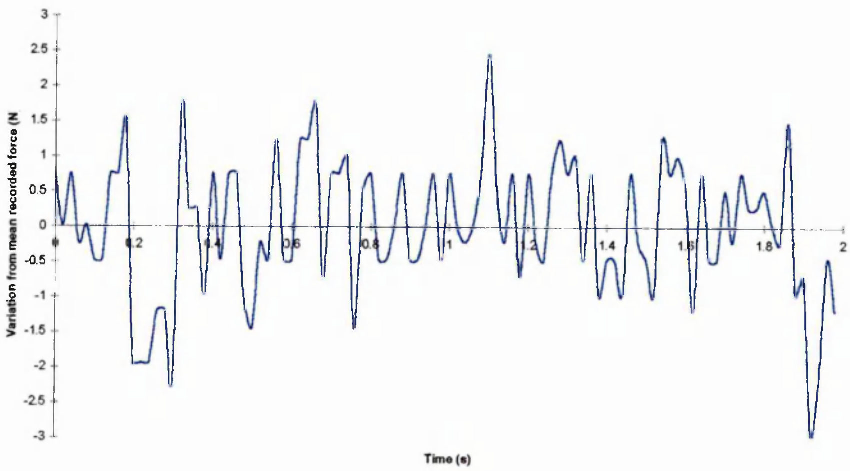


Figure 8.13 Variation in system output from seat section over 2 seconds – loaded with 80kg.

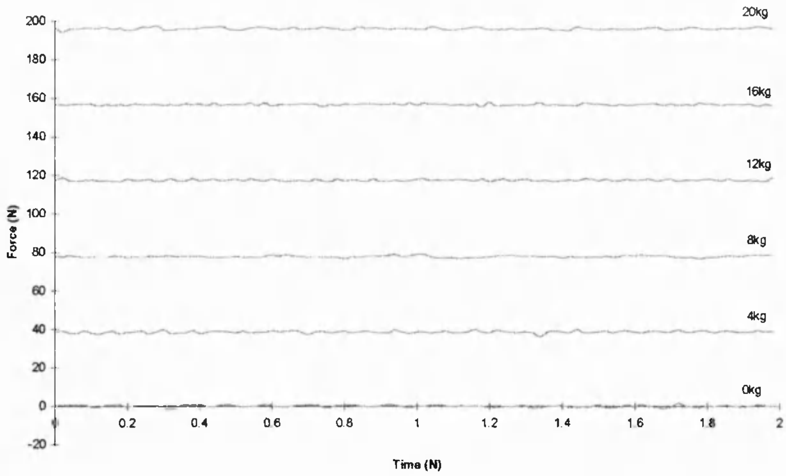


Figure 8.14 System output from arm section over 2 seconds during application of different loads.

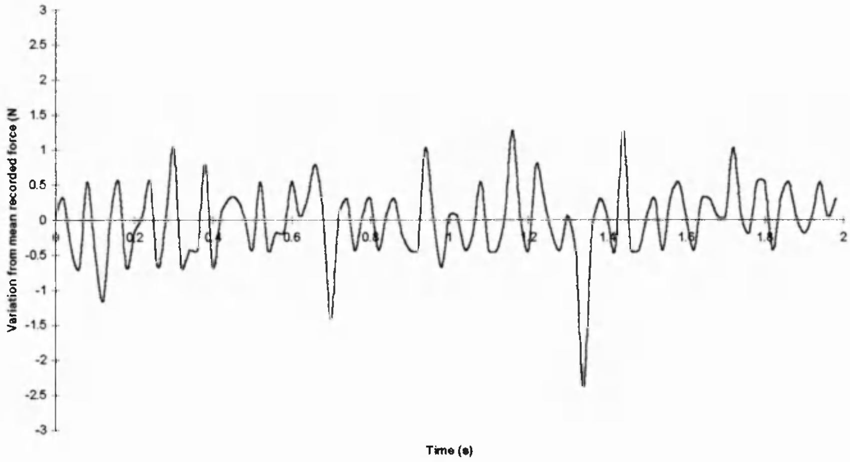


Figure 8.15 Variation in system output from arm section over 2 seconds – loaded with 4kg.

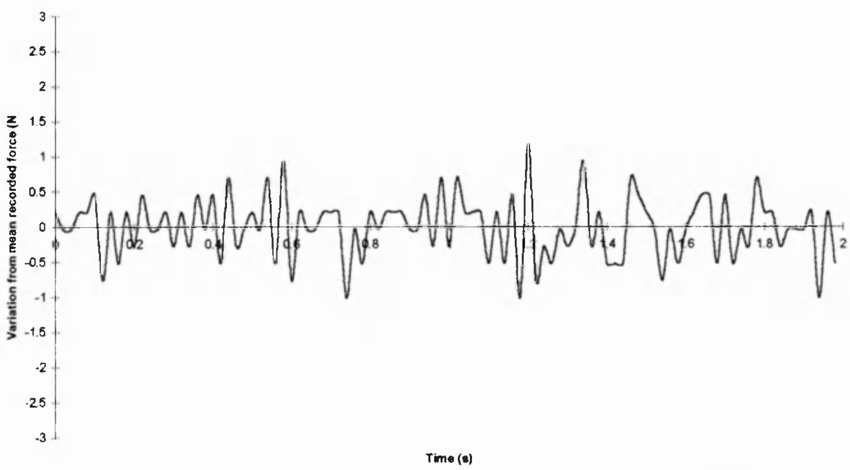


Figure 8.16 Variation in system output from arm section over 2 seconds – loaded with 16kg.

8.2.5 Precision and system stability

Effect of warm up time on system response

To identify the effect of warm up time on the system response, the mean system output from each section of the unloaded measurement system was recorded every 10 minutes for 3 hours. The system was re-zeroed every hour as subject test sessions were not anticipated to be longer than one hour. The standard deviation and range of output from the 1st hour of data collection was larger than that from the 2nd or 3rd hours, for all measurement sections (Table 8.4 and Table 8.5). The maximum error was approximately 11N in the first hour; was less than 3N in the 2nd hour and less than 1.5N in the 3rd hour. It was concluded that the system output from all sections during the first hour after switching the system on was less stable than the system output during the 2nd and 3rd hours after switch on. For all subsequent experiments the power was switched on at least one hour prior to data collection.

	1st hour	2nd hour	3rd hour
Left heel	3.28	0.41	0.18
Left forefoot	2.41	0.20	0.37
Right forefoot	4.03	0.44	0.17
Right heel	1.90	0.31	0.42
Left ischium	0.80	0.84	0.50
Left thigh	0.77	0.63	0.31
Right thigh	0.76	0.59	0.48
Right ischium	0.79	0.60	0.39
Right arm	3.53	0.90	0.28
Left arm	3.48	0.84	0.13

Table 8.4 Standard deviations of system output during hour periods (N)

	1st hour	2nd hour	3rd hour
Left heel	9.02	0.98	0.49
Left forefoot	6.59	0.49	1.22
Right forefoot	11.22	1.22	0.49
Right heel	5.37	0.73	1.22
Left ischium	2.20	2.44	1.46
Left thigh	2.20	1.71	0.98
Right thigh	1.95	1.71	1.46
Right ischium	2.44	1.71	0.98
Right arm	10.00	2.68	0.73
Left arm	10.00	2.44	0.24

Table 8.5 Range of system output during hour periods (N).

Drift with time

The measurement of human performance requires the continuous measurement of data. To investigate the stability of the system output during continuous data collection, data was recorded from all force sections for 40 minutes. To allow the system to record for this maximum length of time the frequency of sampling was reduced to 0.5Hz. The drift was investigated with each section unloaded and loaded with 20kg. The standard deviation of the system output from each section over the 40 minute period (Table 8.6) was similar to the values determined during the investigation of system noise (section 8.2.4). 95% of the output over the 40 minute period was within 2.25N of the mean output. The distribution of the data collected was normal, indicating that there was no systematic drift over time.

Mass applied	Left heel	left forefoot	right forefoot	right heel	left ischium	left thigh	right thigh	right ischium	right arm	left arm
0kg	0.83	0.8	0.92	0.87	0.84	0.86	1.08	0.86	0.57	0.60
20kg	0.87	0.89	0.96	0.87	0.89	1.12	0.88	1.07	0.51	0.61

Table 8.6 Standard deviation of system output (N) over 40 minute period.

8.2.6 Reliability

Although previous experiments demonstrated that the measurement system had a linear response to vertical force, it was necessary to ensure that this finding was repeatable at different time periods. External factors, such as temperature, electrical interference, and the procedure of manually adjusting the baseline (zero) amplification level could have potentially affected the reliability of the system output.

Intra-test session reliability

Loads of 0, 10 and 20kg were applied and removed 10 times in succession to each of the four foot and four seat sections. Loads of 0, 5 and 10kg were repeatedly applied and removed 10 times from the armrests. The mean system output (mean of 1 second of data collection) was recorded from the relevant measurement section following the application of each load. The difference between each of the 10 mean system outputs for the application of each of the 3 loads was determined for each measurement section. Calculation of PCA demonstrated that 80% of the repeated tests of loading with the 3 loads had less than 4.75N difference, 95% of the repeated tests had less than 8.75N difference, and 100% of the repeated tests had less than 10.5N difference (see Table 8.7). The results for the loading and unloading of the sections were similar. The small degree of difference between the repeated measures demonstrates that there was high intra-test session reliability.

	80%	95%	100%
left heel	2.75	8	10.5
left forefoot	2.75	8.75	10
right forefoot	3	5	7
right heel	4.75	6	8
left ischium	3	7	11
left thigh	3	5	9
right thigh	4	6	9
right ischium	4	7	12
right arm	1.75	2.75	3.75
left arm	1.25	2.75	3.5

Table 8.7 The differences between output (N) likely to occur for different values of PCA during 10 repeated loads of 3 different magnitudes to each measurement section.

Inter-test session reliability

In order to mimic the expected time interval between test sessions, data was collected twice per day (morning and afternoon) for 5 consecutive days. Initial data collection was taken from each measurement section with each section unloaded and with each of the foot and seat sections loaded with 20kg and with each of the arm sections loaded with 10kg. This data collection revealed that the values for the PCA were greater when the force sections were loaded. This finding demonstrated the need to explore the reliability across the full measuring range. Since all the measurement sections had had similar responses during the initial experiment, the subsequent investigation was carried out with data from one seat, one foot and one arm section only. Each of these sections were loaded and unloaded and the mean system output recorded, as in the tests of accuracy (section 8.2.3). This was repeated twice per day (morning and afternoon) for 5 consecutive days. The plotting of regression lines and calculation of regression equations confirmed that there was a linear response from each section at each test session (Figure 8.17, Figure 8.18 and Figure 8.19). Calculation of the PCA demonstrated that the value of the PCA did increase as the applied load increased (Table 8.8 and Table 8.9). However, when the PCA was expressed as a percentage of the applied load, the percentage of the PCA decreased as the applied load increased. 95% of the difference between test session results were less than 3.8% of the applied load to the foot and seat sections, and less than 10.2% of the applied load to the arm section. This is equivalent to a difference of 3.75N between the repeated tests on the foot and seat sections, and 2.00N between the repeated tests on the arm section.

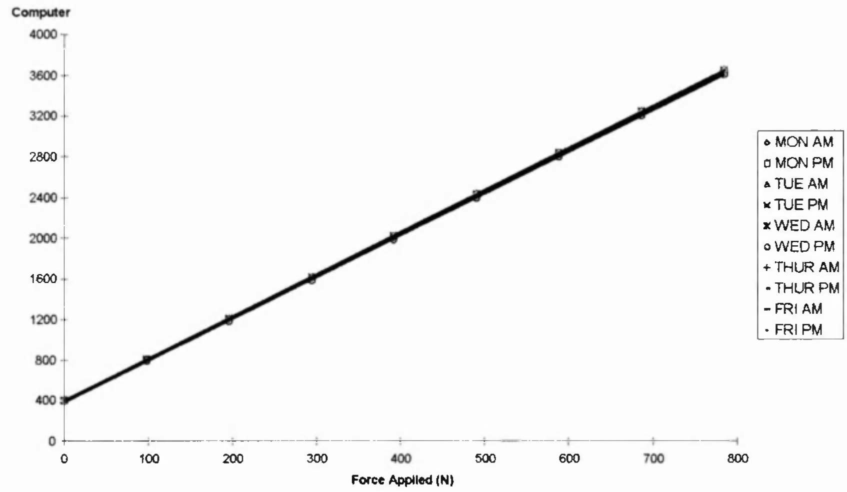


Figure 8.17 Regression lines from different test sessions – foot section.

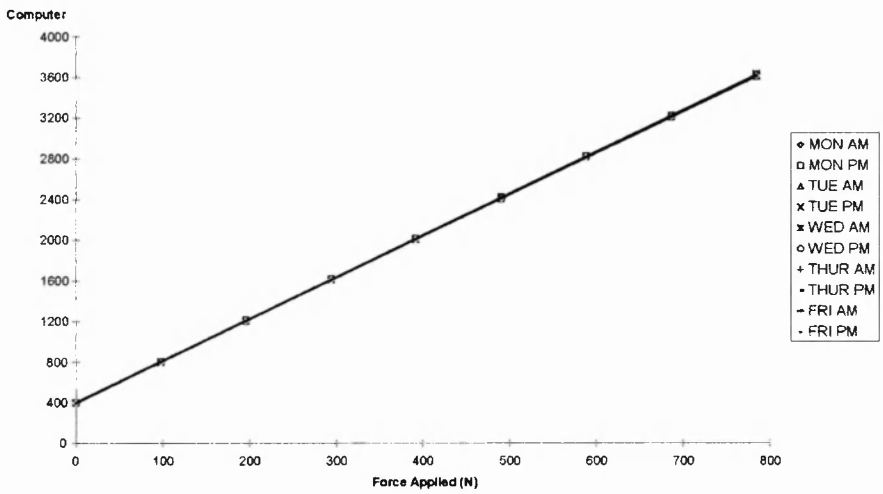


Figure 8.18 Regression lines during different test sessions – seat section.

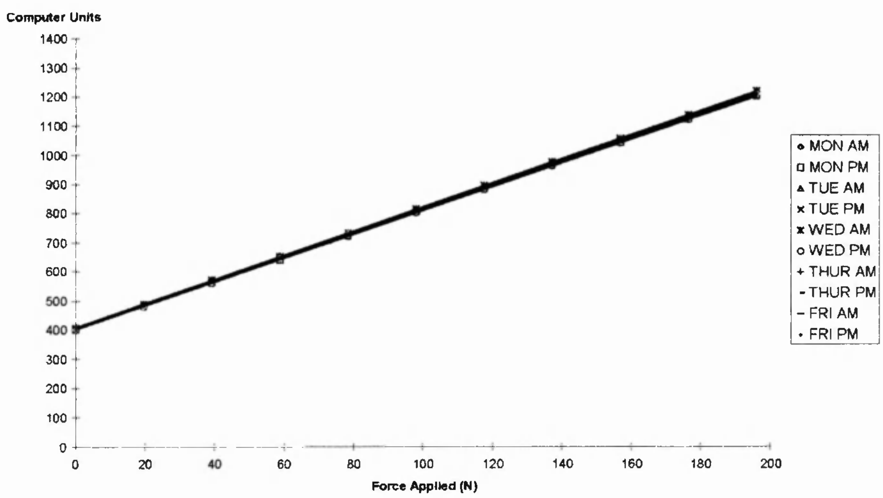


Figure 8.19 Regression lines during different test sessions – arm section.

Mass (kg)	80%	95%	100%	95% PCA as % of load
0	1.25	2	3	-
10	2.25	3.75	5.25	3.82%
20	2.75	4.5	6.25	2.29%
30	3.5	6.25	8.75	2.12%
40	4	7.5	10	1.91%
50	4.75	8.75	11.75	1.78%
60	5	8.75	11.25	1.49%
70	5.75	9.5	12	1.38%
80	5.75	10	11.5	1.27%

Table 8.8 The differences in output (N) likely to occur for different values of PCA during increasing load applications on foot and seat sections during different test sessions.

Mass (kg)	80%	95%	100%	95% PCA as % of load
0	1.5	1.5	1.75	-
2	1.5	2	2.25	10.19%
4	2	2.5	2.75	6.37%
6	2	2.75	3.25	4.67%
8	2	2.75	3.25	3.50%
10	2.5	3.25	3.5	3.31%
12	2.5	3.5	3.75	2.97%
14	2.75	3.75	3.75	2.73%
16	3	3.75	4	2.39%
18	3.25	4	4.25	2.27%
20	3.25	4	4.5	2.04%

Table 8.9 The differences in output (N) likely to occur for different values of PCA during increasing load applications on arm section during different tests sessions.

8.2.7 Point of application

Since the point of application of a force during the measurement of human performance could occur at any point on the individual sections, it was necessary to determine the precision of the output at different points across each section.

Foot and seat sections

A load of 20kg was placed through a small object (radius approximately 0.005m) to 9 points spread in a rectangular grid over the surface of each section. The points were spread evenly, with 8 points 0.02m from the edge of the section and the 9th point in the centre of the section. The mean system output (mean of 1 second of data collection) was recorded with the load on each point of application. A systematic difference in system output was found across each force section (Table 8.10). The maximum 95% agreement level for the differences in output across one section was 10.5N (Table 8.11). 10.5N is equivalent to approximately 5.4% of the applied load. Thus, variations in the point of application, could potentially lead to systematic errors of up to 5.4% of the applied load, when the centre of pressure of the applied force was at the extreme of the section.

right ischium					left ischium
1.95	0.24	0.00	-2.55	-1.82	-0.60
0.98	0.00	-1.22	-0.11	-0.60	0.62
0.00	-0.73	-1.22	0.14	1.36	3.55
-3.58	-1.87	-0.41	-4.66	-3.20	-1.25
-1.63	-0.16	1.30	-2.22	-0.27	1.92
1.30	2.52	2.52	2.17	3.39	4.12
right thigh					left thigh
right heel					left heel
3.27	2.09	-0.94	0.36	2.83	4.87
-1.42	1.37	-1.47	-1.78	0.75	1.99
-1.13	0.56	-2.34	-6.43	-2.03	-0.56
-5.30	0.06	-0.76	0.47	0.62	1.92
-5.93	3.39	2.37	-0.37	-0.03	1.12
-4.82	6.44	4.56	-1.91	-1.07	-0.75
right forefoot					left forefoot

Table 8.10 Difference between each of the 9 points of application on each foot and seat section and the mean output for that section (N).

	80%	95%	100%
left heel	6.00	9.50	11.5
left forefoot	2.25	3.25	4.00
right forefoot	8.75	10.50	12.5
right heel	3.75	4.75	5.75
left ischium	3.25	5.50	6.25
left thigh	5.75	8.25	9.00
right thigh	4.25	6.25	6.25
right ischium	2.00	3.25	3.25

Table 8.11 Difference in output (N) likely to occur for different values of PCA during application of load to 9 point on each measurement section.

Arm sections

Durward (1994) reported a systematic error in the system output when increasing loads were applied to the armrests. In order to investigate this finding, and the effects of the point of application along the arm rests, it was necessary to record the output during the loading and unloading of the arm sections at different intervals along their length. Loads of 0 to 20kg were sequentially loaded and unloaded, in 2kg stages, to the front, middle and back of the arm sections. The mean system output (mean of 1 second of data collection) was recorded for each load applied. This confirmed that there was a decrease in the gradient of the line of best fit towards the middle and rear of both arm sections (Figure 8.20 and Figure 8.21). The response of the arm rests to the loading and unloading was similar. The use of the mean gradient (4.10) to convert data from computer units to newtons, when the vertical force is applied to the rear of the arm rests could introduce errors of up to approximately 14.3N during the maximum expected load of 20kg. This is equivalent to approximately 7.3% of the applied load, when the centre of pressure of the applied force was at the extreme of the section.

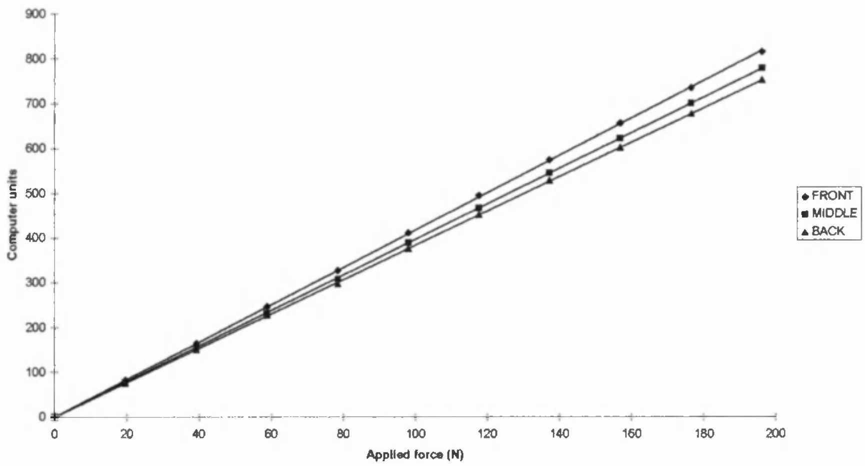


Figure 8.20 Lines of best fit during the loading of different point on the right arm rest.

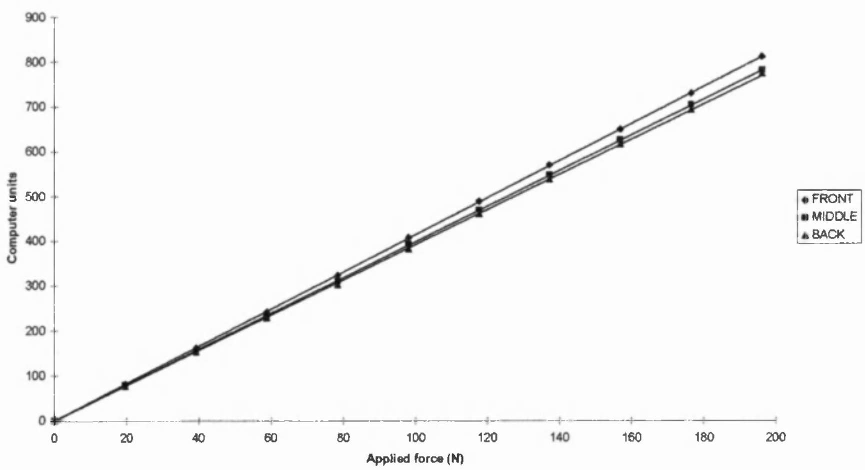


Figure 8.21 Lines of best fit during the loading of different point on the left arm rest.

8.2.8 Horizontal forces

As the measurement system was to be used for the measurement of dynamic movement it was possible that horizontal forces would be applied to the measurement sections. It was necessary to investigate the effects of the application of horizontal forces, to determine whether they caused any change to the system output. The magnitude of horizontal forces that could potentially occur when a subject sits, stands, rises to stand or sits down were difficult to predict. However studies of human walking have found that horizontal forces under the feet may be up to 25% of body weight (Paul, 1997). Therefore, a pulley system was used to apply sequentially increasing horizontal loads of up to 20kg to one of the foot and one of the seat sections. The applications of horizontal forces to the foot and seat sections did not appear to result in a systematic response from the output (Figure 8.22). The equations of the line of best fit through the recorded points demonstrated gradients very close to zero (Table 8.12). The standard error of the estimate and maximum residual were both low, indicating that there was little change in system output with the application of forces along the horizontal plane. It can therefore be concluded that the application of a horizontal force to these measurement sections has a negligible effect on system output.

	Equation of line of best fit	Standard error of the estimate (N)	Maximum residual (N)
Foot section - Fx	Y = 0.008X	0.52	0.97
Foot section - Fy	Y = 0.001X	0.45	0.93
Seat section - Fx	Y = 0.003X	0.51	0.86
Seat section - Fy	Y = -0.004X	0.51	0.56

Table 8.12 Equation of line of best fit, standard error of the estimate and maximum residual for system output during application of increasing loads in the horizontal plane.

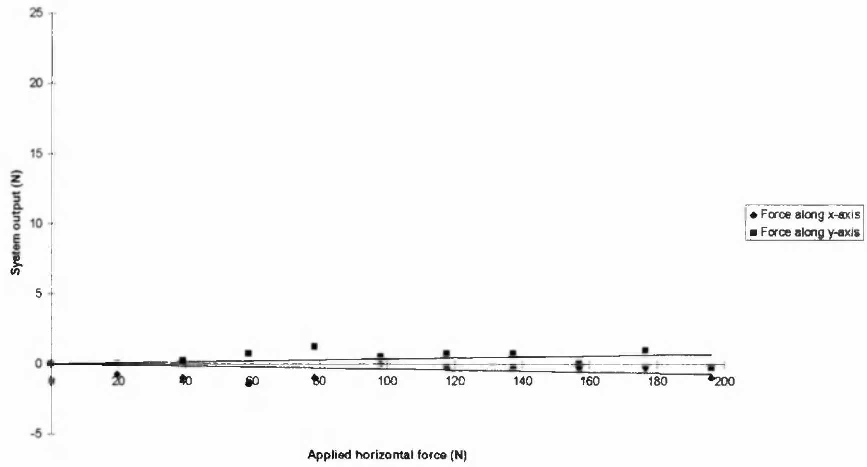


Figure 8.22 System output during application of horizontal forces to seat section.

8.2.9 Moments

Similar to the application of horizontal force, it would be possible for a subject to apply turning moments around the centre of each measuring section. It was therefore necessary to investigate whether application of turning moments would affect the system output. The turning moment generated under the feet during human walking is approximately 20Nm (Paul, 1997). The system output was tested with the application of turning moments of up to 20Nm around the x-, y- and z-axes of the force plate. Force couples were used to provide pure turning moments, on one foot and one seat section. The mean system output (mean of 1 second of data collection) was recorded with each sequential increase to the turning moment. As the applied turning moments were increased the error in system output was also found to increase (Figure 8.23 and Figure 8.24). For turning moments around the x- and y-axes, turning moments of 20Nm were found to cause errors of up to 8.5N. A turning moment of the same magnitude around the z-axis was found to cause errors of up to 23N. Although this indicated a potentially large source of error, and it was necessary to be aware of this, turning moments of the magnitude explored in this investigation were unlikely to occur in the proposed measurement regime. The activities of sitting, standing, rising to stand and sitting down are activities which are performed in the midline and should therefore not involve the production of large turning moments. In the activity of reaching the majority of the subject's weight will pass through the chair, and will not be passing through a specific small area at which a large turning moment could be created. In this investigation pure turning moments were applied using a system of string and pulleys, and although human subjects could potentially create a turning moment, it is unlikely to be of the same magnitude.

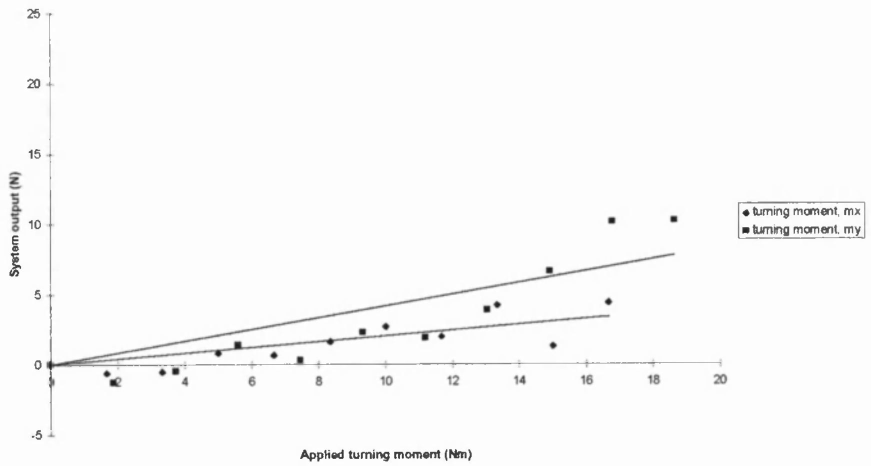


Figure 8.23 System output during the application of pure turing moments around the x-axis (mx) and y-axis (my) of a foot section.

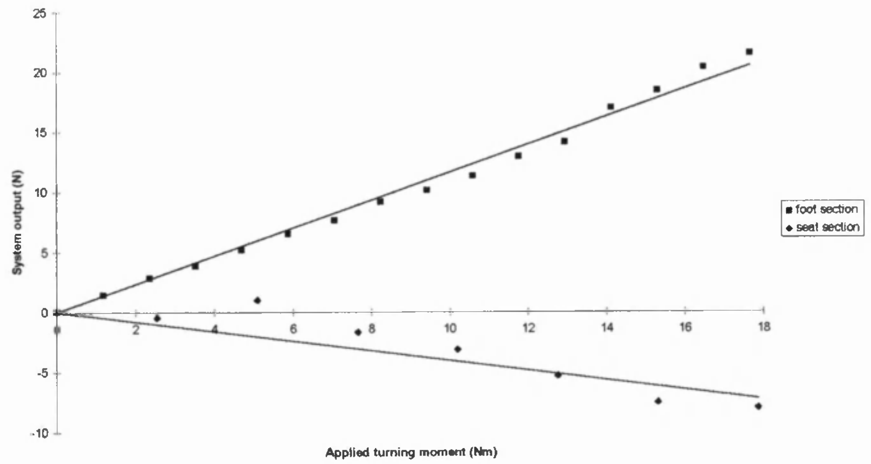


Figure 8.24 System output during the application of pure turing moments around the z-axis (mz) to a foot and a seat section.

8.2.10 Dependence of system output

Since the measurement sections all work in close proximity it was necessary to determine whether the system output from each individual section was independent from the other sections.

Dependence of force sections

A load of 20kg was placed on to one of the measurement sections. Data collection was started prior to the application of the load and continued for approximately 5 seconds after the application. This allowed for the identification of the influence of the load both during and after application. During the application of the load to the foot sections the output from all the other sections was investigated. However, the nature of the measurement system made it impossible for the investigator to apply the load to the seat and the arm sections without standing on the foot sections. Therefore during the application of the load to the seat and arm sections the output from the adjacent seat and arm sections was investigated, but not the output from the feet sections. The mean and standard deviation of output from each of the sections before, during, and after the application of each load were determined. The results demonstrated that the change in mean system output from the measurement sections during and after the application of a 20kg load to any one of the adjacent sections was under 2N (Figure 8.25, Figure 8.26 and Figure 8.27). Changes of this magnitude can be attributed to system noise. The standard deviation of the system noise from the measurement sections did not change by more than 1N between the initial 2-second period and the 2 seconds during or after the application of the load. This indicates that 95% of the system output will not vary more than 2N from the mean. This change can therefore also be attributed to random system noise. In conclusion, there was no dependence of the force measurement sections on the load applied to adjacent sections.

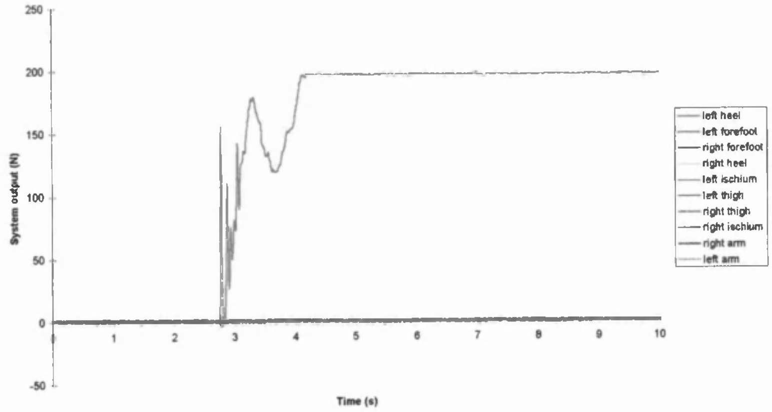


Figure 8.25 System output from measurement sections before, during and after the application of a load to the left heel section.

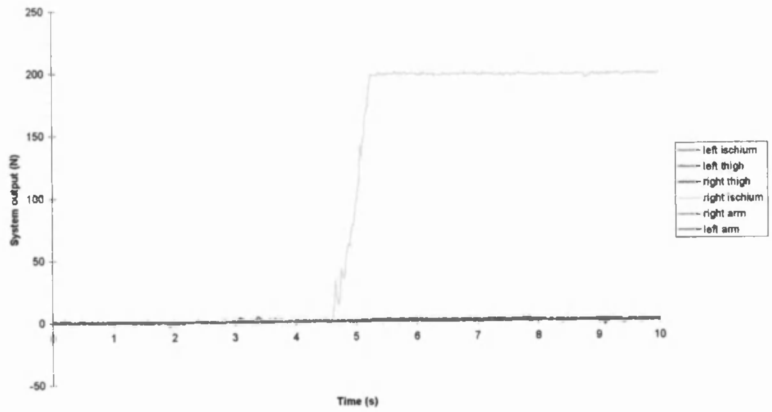


Figure 8.26 System output from seat and arm sections before, during and after the application of a load to the right ischial section.

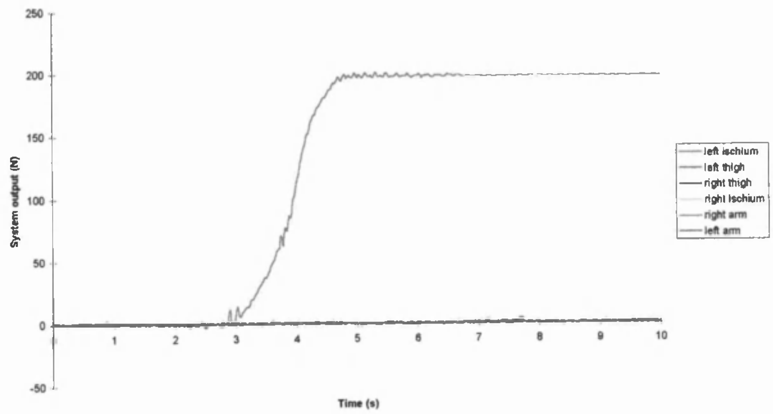


Figure 8.27 System output from seat and arm sections before, during and after the application of a load to the right arm section.

Effect of seat upholstery on dependency

The seat sections had a series of foam wedges and a vinyl cover which were utilised when the system was used with human subjects. The foam wedges were designed to ensure that they were unable to touch the adjacent sections when compressed. However, the vinyl cover loosely covered all the wedges and was therefore assessed to be a potential source of interference between the system output of the four seat sections. The effect of applying loads to one side of the seat on the output of the adjacent sections, with the upholstery in place, was therefore investigated. The upholstery made it impossible to apply known loads to individual seat sections: the effects of loading the right side (right ischium + right thigh) on the system output from left side (left ischium + left thigh) was explored. The right side of the seat was sequentially loaded, up to 80kg, and the mean system output (mean of 1 second of data collection) was recorded from the left side. This was repeated with the left side unloaded and loaded with 10kg and 20kg. The results illustrated that there was a systematic increase in output from the left side as the load on the right side was sequentially increased (Figure 8.28). This increase was not dependent on the magnitude of the load applied to the left side. The maximum increase in output from the left side was approximately 5.5N, when a load of 80kg was applied to the right side (Table 8.13). The increase in system output from the left side was a maximum of 1.0% of the load applied to the right side (Table 8.14). In conclusion; the use of the upholstery can potentially result in errors in the system output from the sections adjacent to the loaded section of approximately 1% of the load on the loaded sections.

Mass applied	0kg load	10kg load	20kg load
0kg	0.00	0.00	0.00
20kg	1.44	1.67	2.02
40kg	2.54	2.91	2.52
60kg	4.22	3.78	3.63
80kg	5.21	5.50	4.99

Table 8.13 Difference in system output from left seat sections during loading of right seat sections, with static loads applied to left side, taking output when right side unloaded as baseline (N).

Mass applied	0kg load	10kg load	20kg load
20kg	0.73%	0.85%	1.03%
40kg	0.65%	0.74%	0.64%
60kg	0.72%	0.64%	0.62%
80kg	0.66%	0.70%	0.64%

Table 8.14 Difference in system output from left seat section expressed as percentage of load applied to right seat.

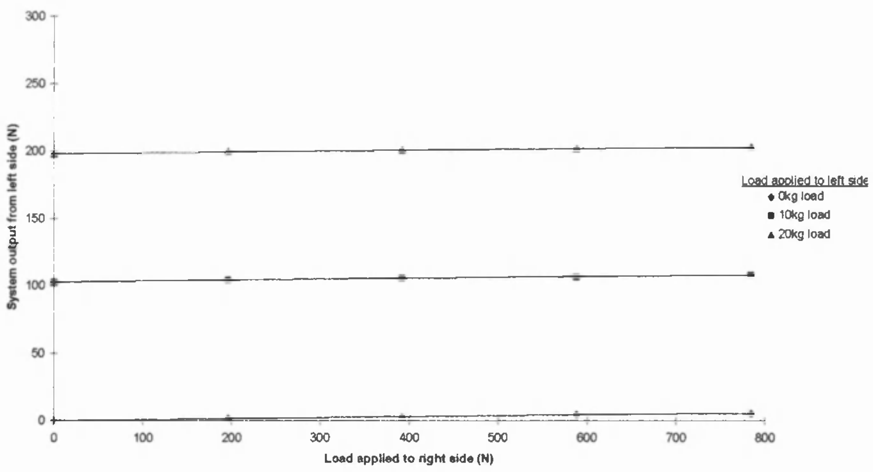


Figure 8.28 System output from the left seat sections during the loading of the right seat sections, with static loads applied to the left side (N).

8.2.11 Dynamic response

During studies of human movement there is the potential for a sudden dynamic force to be applied to the measurement system. It was therefore necessary to investigate the response of the measurement system to a sudden dynamic force. A 10Kg mass was attached to a spring. The spring was positioned so that the mass just hit the selected measurement section when released from the shortened position. The mass was held at the position where the spring was shortened, and was then released. After it had hit the measurement section once, the mass was removed so that it was unable to hit the measurement section again. During this procedure data was recorded from all measurement sections and continued for approximately 5 seconds following the release of the mass. This procedure was carried out with the dynamic load applied to one foot and one seat section. A sudden peak in system output occurred in the section to which the dynamic load was applied (Figure 8.29 and Figure 8.30). The maximum output from the left heel section was approximately 31N, and the maximum output from the left thigh section was approximately 73N. The differences in the maximum output from these sections was likely to be directly related to the subjective element of the application of the load, rather than from errors in output. The system output from these two sections continued with a smaller negative peak (trough), and some oscillation around the zero point. This oscillation was observed to be damped in a very short time period (less than 0.03s). Some vibration also occurred in the surrounding force sections. In the seat sections a small amount of oscillation was observed to initiate immediately after the onset of the load to the left thigh section. The oscillations from the left ischial, right thigh and right ischial sections had a range of approximately 18N, 33N and 17N respectively. The oscillations from these measurement sections were observed to be damped in a similar period of time to the oscillations in the left thigh section. In the feet sections the magnitude of the oscillations in the left forefoot, right forefoot and right heel sections were observed to have ranges of approximately 52N, 27N and 52N respectively. The range of output from the left heel section was approximately 40N. Comparing this with the results from the seat section it can be observed that the adjacent sections in the foot sections had a greater response than the adjacent sections in the seat sections. The differences between the response to a dynamic force by the foot and seat sections can be hypothesised to be directly related to the construction of the system. The seat sections are suspended on a frame consisting of 4 metal legs, which will act to dissipate the dynamic force quickly. The foot sections are mounted within a wooden case, placed on the floor, which is less able to dissipate the vibrations that therefore dissipate through the adjacent sections. However, regardless of the method of dissipation of the dynamic load, both sections demonstrated that they were highly damped, and all oscillations ceased after a very short period of time (less than 0.3s). Such rapid changes in force are unlikely to occur in the measurements of human movement and the tests indicate that the response of the system can effectively monitor the slower changes in force occurring during functional activity.

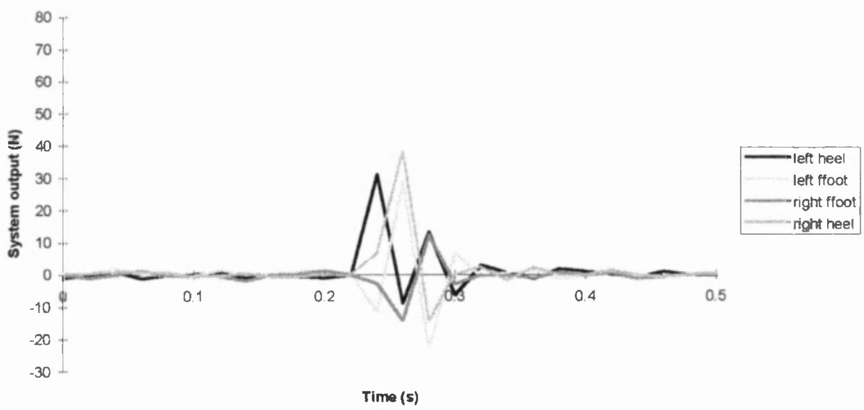


Figure 8.29 System output in response to application of dynamic load (feet section).

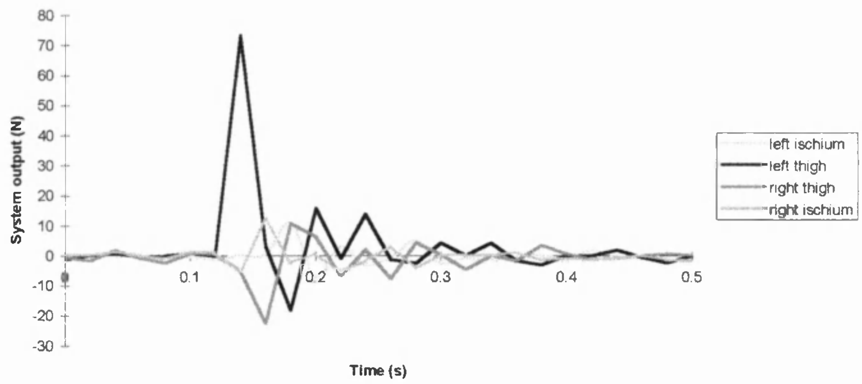


Figure 8.30 System output in response to application of dynamic load (feet section).

8.2.12 External Vibration

As the subject measurements were to be taken in a busy physiotherapy gym, it was necessary to explore the influence of external vibration from the surrounding environment on the system output. System output was recorded as specific activities were carried out within the gym. These activities included the movement of wheelchairs in and out of the gym; staff walking around the gym; and the movement of treatment plinths within the gym. Data was collected from each of the unloaded sections. Examples of the data collected are given in Figure 8.31 - Figure 8.34. The maximum standard deviation of the system output from any of the measurement sections during all of the periods of potential external vibration, was a maximum of 0.89N. This indicated that, even during periods of activity in the gym, 95% of the system output was within 1.8N of the mean. In the earlier experiment into system noise (section 8.2.4), it was concluded that 95% of the system output was within 2N of the mean. Thus the system output collected during periods of activity in the gym does not appear to be affected by external noise (vibration). It is therefore concluded that activity in the gym (external vibration) does not affect the accuracy of the system.

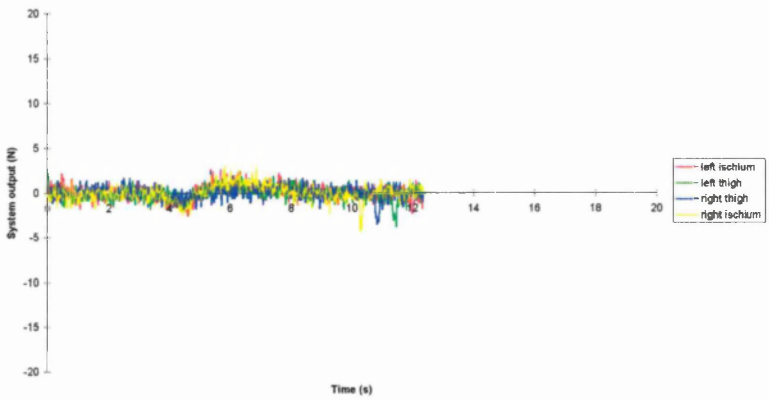


Figure 8.31 System output during subject walking around measurement system – seat sections.

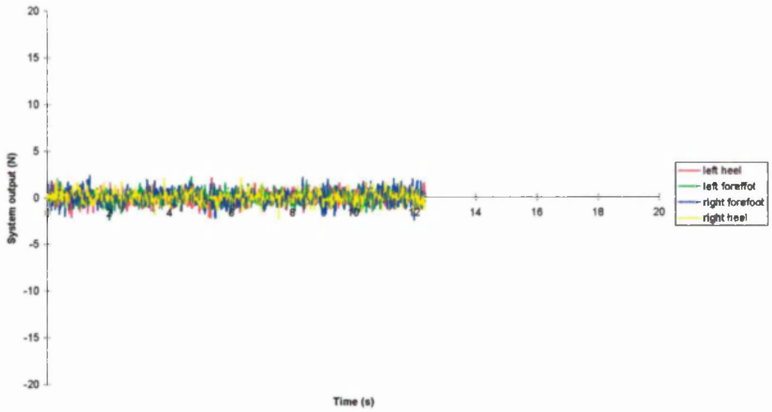


Figure 8.32 System output during subject walking around measurement system – feet sections.

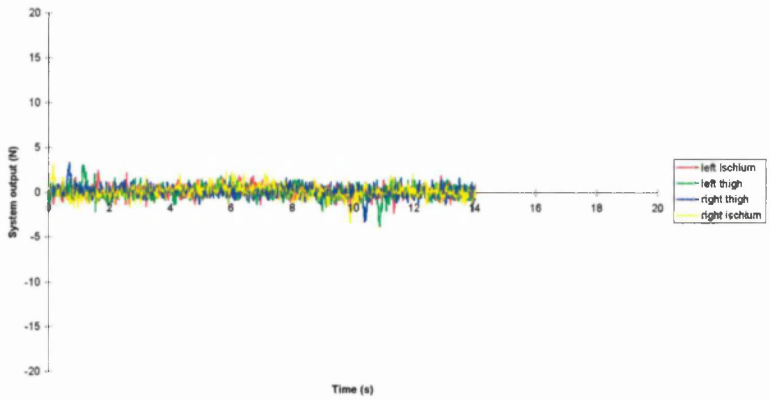


Figure 8.33 System output during wheelchair being pushed past measurement system – seat sections.

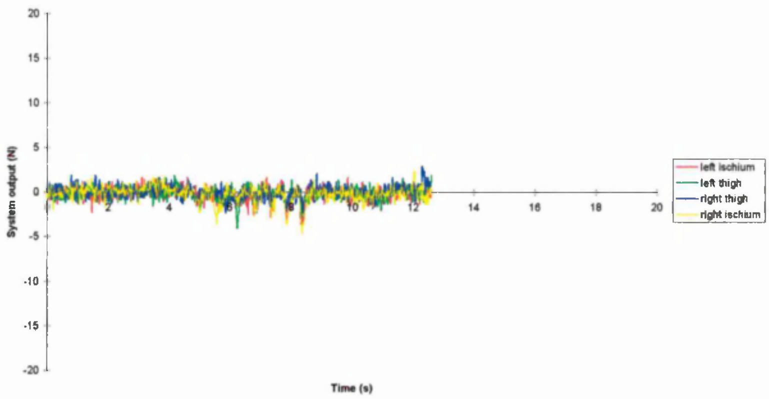


Figure 8.34 System output while back rest of chair pushed – seat sections.

8.3 Analysis of objective data

Having ascertained the accuracy and precision of the measurement system, it was necessary to define the method with which objective measurements of human posture and movement would be analysed.

8.3.1 Symmetry index

The measurement system recorded the vertical force through 10 measurement sections, sampling at 50Hz. For the purpose of this study, where the aim was to investigate the symmetry of weight distribution during posture and movement, the force data was converted into an index of symmetry. In the review of literature it was determined that many indices of symmetry can be inappropriate (chapter 3). An index that was found to be appropriate for the assessment of the symmetry of weight distribution was identified in section 3.5.2. This index was:

For healthy subjects:-

$$\text{Symmetry Index, SI} = \frac{(\text{weight on left} - \text{weight on right})}{(\text{weight on left} + \text{weight on right})}$$

Or, in the case of hemiplegic subjects:-

$$\text{Symmetry Index, SI} = \frac{(\text{weight on unaffected side} - \text{weight on affected side})}{(\text{weight on unaffected side} + \text{weight on affected side})}$$

This symmetry index was calculated using the sum of the vertical forces from the left and right sides of the measurement system.

$$\text{i.e. SI} = \frac{(LH+LF+LI+LT+LA) - (RH+RF+RI+RT+RA)}{(LH+LF+LI+LT+LA) + (RH+RF+RI+RT+RA)}$$

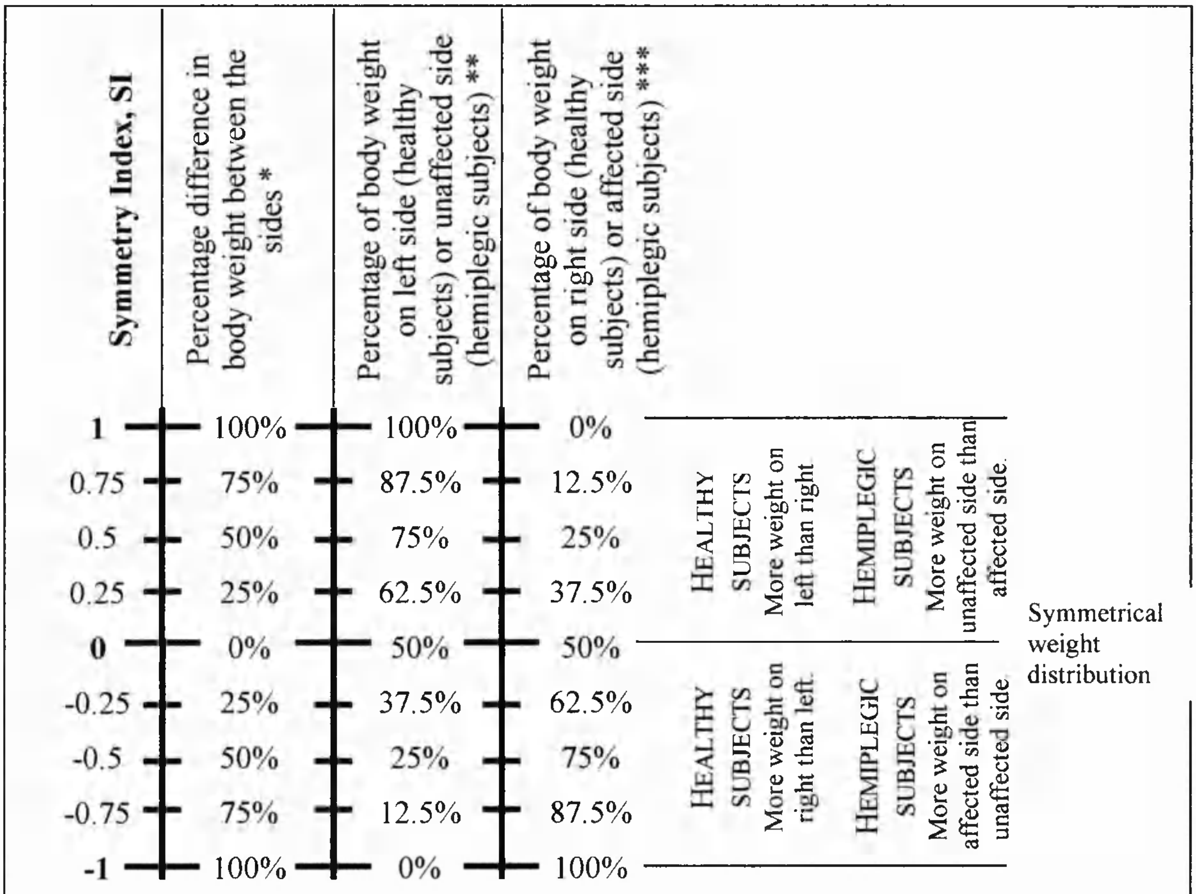
Where:-

LH = force through left heel section (N)
LF = force through left forefoot section (N)
LI = force through left ischium section (N)
LT = force through left thigh section (N)
LA = force through left arm rest (N)

RH = force through right heel section (N)
RF = force through right forefoot section (N)
RI = force through right ischium section (N)
RT = force through right thigh section (N)
RA = force through right arm rest (N)

All recorded force data was converted into the symmetry index.

This index provided a continuous scale from –1 to 1, with 0 representing symmetrical weight distribution. This index served as a simple representation of the symmetry of weight distribution, and could easily be converted into measures of the percentage of body weight borne through either side of the body. The formulae for converting the symmetry index into values of the percentage of body weight through either side are illustrated in Figure 8.35.



* Percentage difference in body weight between the sides = SI × 100%

** Percentage of body weight on left side (healthy subjects) or unaffected side (hemiplegic subjects) = [0.5 + (SI/2)] × 100%

*** Percentage of body weight on right side (healthy subjects) or affected side (hemiplegic subjects) = [0.5 – (SI/2)] × 100%

Figure 8.35 Conversion of values of the symmetry index into percentage body weight between the sides and percentage body weight on each side.

For the measurement of the functional tasks, data was collected over continuous periods of time. Analysis of the variation in the data over time would provide a representation of the changes in the symmetry of weight distribution over time. During the maintenance of a posture, changes in symmetry over time have been argued to represent postural sway (Black et al, 1982; Ring et al, 1988; De Weerdt et al, 1989; Ekdahl et al, 1989; Sackley, 1990, 1991; Sackley and Lincoln, 1991). However, the aim of this study was primarily to investigate the symmetry of weight distribution, rather than postural sway. Subsequently, data analysis was limited to the exploration of the symmetry of weight distribution and investigation of changes in the symmetry index over time as a result of postural sway was not carried out.

8.3.2 Analysis of different types of functional tasks

Objective measurements of sitting, standing, rising to stand, sitting down, reaching to the same side and reaching across to the opposite side were carried out. There are fundamental differences in the movement strategies for these different tasks and hence there were different methods of analysis of the data recorded during the different tasks.

Sitting, standing, rising to stand and sitting down can be argued to be "symmetrical" tasks. These tasks are generally assumed to be carried out within a symmetrical posture or with symmetrical movement patterns. It was therefore considered that analysis of the average symmetry index over the period of data collection would provide an appropriate measure of the symmetry of weight distribution for each of these tasks. The mean symmetry index was determined for the periods of sitting and standing, and for defined phases of rising to stand and sitting down. An advantage of the use of the mean symmetry index as a measure of outcome for each of these four tasks was that it allowed direct comparison of the symmetry of weight distribution during these different functional tasks.

In contrast to the analysis of the "symmetrical" tasks, the aim of reaching to the same side and reaching across to the opposite side was to achieve maximum lateral weight transference and then to return to a sitting posture. The mean symmetry index during reaching to the same side and reaching across to the opposite side was therefore not appropriate in the analysis of the reaching tasks. Since there was no evidence pertaining to the assessment of the symmetry of weight distribution during reaching tasks available in the literature, a process of exploration of the pattern of the symmetry index during the reaching tasks was carried out. The aim of this exploration was to confirm that the movement of reaching produced a distinct and reproducible pattern and, subsequently, to identify the pertinent outcome measures for the analysis of the movement. The selected outcome measures for the analysis of the reaching tasks are outlined in section 15.1.3.

8.3.3 Statistical tests and analysis

For the healthy and hemiplegic subject data, statistical comparison of the association between the measured outcome variables from the different tasks was carried out. Pearson's correlation coefficient was calculated to determine the strength of the association between the outcome variables from the different tasks.

Multiple regression was carried out to explore the relationship between independent variables (gender, age, age-group, height, body mass, lower-leg length, dominant hand) and the measured outcome variables from the healthy subjects.

The relatively low number of hemiplegic subjects involved, and the large variation between the subjects, limited the use of statistical tests in the analysis of data. Additional limitations were placed on statistical analysis by the high number of hemiplegic subjects who were unable to carry out the tasks of standing, rising to stand and sitting down, and by the number of subjects who were discharged from the trial before 7 weeks of measurements had been completed. Classification of the hemiplegic subjects into 3 simple groups of ability ("unable", "abnormal", "normal"; see section 11.3.4) included a maximum number of subjects and hence enabled the use of the Chi-squared test to determine the statistical significance of the differences in the ability of the subjects in the control group and practice group. However, as a consequence of the relatively low subject numbers, the analysis of the data from the clinical trial was principally carried out with descriptive statistics. The use of descriptive statistics, combined with the use of the classification system and Chi-squared test, allowed identification of the magnitude of the symmetry index during the different tasks; the observation of trends and patterns in the results; the comparison of the data from the healthy and the hemiplegic subjects; and the comparison of the ability of subjects in the control group and practice group.

As has been identified, an advantage of the use of the symmetry index was that it allowed direct comparison between the symmetry of weight distribution during different functional tasks. To assist the descriptive process and to allow easy comparison between the symmetry index during the different functional tasks, all graphs depicting aspects of the symmetry index were plotted with the full symmetry index scale (1 to –1) on the relevant axis. In addition to allowing easy comparison between the symmetry values during different tasks, the depiction of the full symmetry index scale had a further advantage for the descriptive analysis of the symmetry data. Plotting the symmetry indices from subjects during any functional task demonstrated two important aspects pertaining to the symmetry of weight distribution. The first of these was the variation between the subjects: this could be observed with any axis scale that included the maximum and minimum symmetry index values for that particular group of subjects. However, the second aspect of note, pertaining to the symmetry of weight distribution during a functional task, was the position of the data on the entire symmetry index scale. The position of symmetry data on the full symmetry index scale provides a visual representation of the magnitude of the symmetry of weight distribution. Plotting all graphs on the full symmetry index scale permitted the observation of the variation between subjects and the observation of the magnitude of the symmetry of weight distribution.

9. Methods

9.1 Testing protocol

Objective measurement of the symmetry of weight distribution during sitting, standing, rising to stand and sitting down, and the weight transference during reaching out to the side from a sitting position, was recorded using the measurement system. A sampling frequency of 50Hz is generally reported in studies of human gait. Mizrahi et al (1985) found that the frequency of sway in healthy and hemiplegic subjects did not exceed approximately 7Hz during standing. For the relatively slow movements tested in this study a higher frequency of data collection is unlikely to provide any further information. Therefore, for all tests in this study the frequency of data collection was 50Hz.

9.1.1 Testing: healthy subjects

Testing took place at a time convenient for the subject, either within the Human Performance laboratory at Queen Margaret College or within the physiotherapy gym at the Western General Hospital. A quiet and undistracting environment was maintained during all tests. The tests were carried out in a strict order following standardised protocol. The test order is illustrated in Figure 9.1.

A.) Tests of symmetry of weight distribution: healthy subjects

1. Sitting.

The subject was requested to sit in a comfortable position in the chair. The tester adjusted the position of the foot sections so that the subject's feet were positioned in the centre of the measurement section. The subject was requested to sit with hands in lap, upright away from the backrest of the chair and looking straight forwards at a black marker-cross (placed 2m in front of the centre of the front of the chair at a height of 2m). The subject was requested to maintain this position until instructed to relax. 10 seconds of data was collected while the subject maintained this position.

2. Rising to stand.

The subject was instructed to sit comfortably, with hands in lap, looking straight forwards at the marker-cross, until given the command "stand up". On this command the subject was to stand up "as you do normally", and remain standing looking at the marker-cross. Subjects requesting clarification of the commands were reminded that their feet had to remain in position on the foot plate sections.

Data collection was started approximately 2-3 seconds prior to the command "stand up". On giving this command the tester pressed the event-marker switch. When the tester assessed that the subject had finished the movement of rising to stand the event-marker switch was pressed again. Data collection continued for a further 4 seconds, to ensure that sufficient data was present to enable objective determination of the end of the movement.

3. Standing.

The subject remained standing following the test of rising to stand. The subject was requested to stand upright, hands by side, looking straight forwards at the marker-cross. The subject was requested to maintain this position until instructed to relax. 10 seconds of data was collected while the subject maintained this position.

4. Sitting down.

The subject remained standing following the previous test. The subject was instructed to stand comfortably, with arms by side, looking straight forwards at the marker-cross, until given the command "sit down". On this command the subject was to sit down "as you do normally", and remain sitting looking at the marker cross. Subjects requesting clarification of the commands were reminded that their feet had to remain in position on the foot plate sections.

Data collection was started approximately 2-3 seconds prior to the command "sit down". On giving this command the tester pressed the marker switch. When the tester assessed that the subject had finished the movement of sitting down the marker switch was pressed again. Data collection continued for a further 4 seconds, to ensure that sufficient data was present to enable objective determination of the end of the movement.

These 4 tests (sitting – rising to stand – standing – sitting down) were repeated in this order until 3 tests of each activity had been completed.

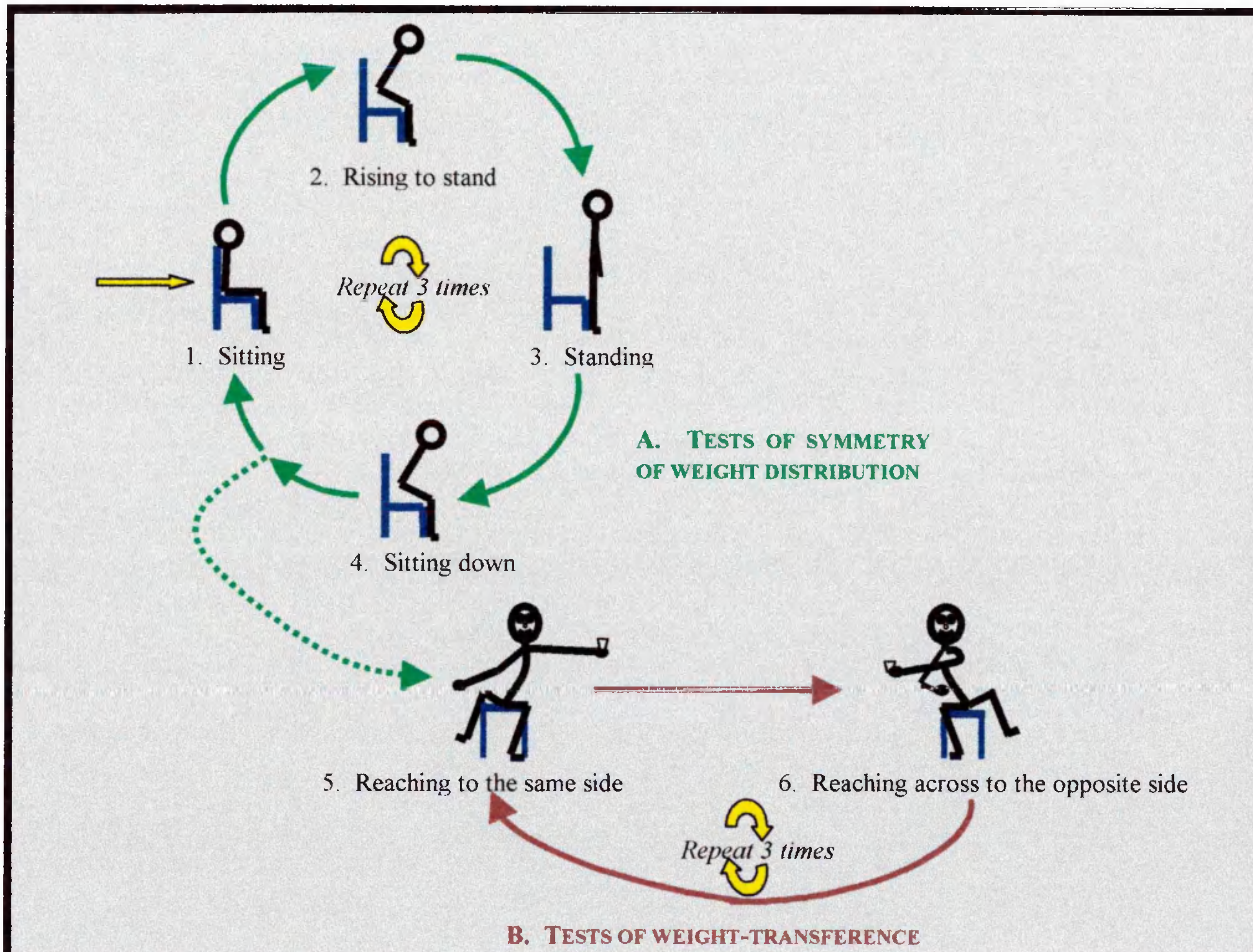


Figure 9.1 Sequence of tests for healthy subjects.

B.) Tests of weight-transference in sitting: healthy subjects

Each subject was assigned a "reaching" arm for the tests of weight-transference in sitting. The purpose of assigning a "reaching" arm was to mimic the ability of stroke patients. Many stroke patients with recently acquired hemiplegia lack the ability to execute voluntary movement with the hemiplegic arm. Reaching therefore has to be carried out with the unaffected arm, regardless of arm dominance. Since the probability of a patient having left or right hemiplegia is approximately equal and can be assumed to occur randomly, the "reaching" arm of the healthy subjects was assigned randomly. A blocked randomisation procedure was used to ensure that equal proportions of the subjects were assigned the left and right arm.

5. *Reaching out to the same side*

The subject remained sitting following the last test of sitting down. A table was positioned level with the front of the chair. The table was a standard folding "pasting table" that was commercially available. The table was selected as the lightweight nature of the table prevented subjects leaning through the table, and using upper limb activity to assist the reaching movement. The folding nature of the table was advantageous due to the limited space available within the clinical setting. A thick white line was drawn along the length of the table 0.10m from the edge nearest the chair, with it's centre marked and lined up with the mid-line position of the chair. A small plastic cup was positioned over the marked mid-point. The subject was requested to sit comfortably, with hands in lap, until the command "go" was given. On this command the subject was to pick up the cup with the "reaching arm" and reach out to the same side (to the side of the reaching arm) "as far as possible", place the cup down on the line and return to "sit in the middle". If a subject requested clarification the instructions were repeated and they were informed to do the movement "as you would naturally".

In order to ensure that a period of quiet sitting was recorded prior to the movement, data collection was started approximately 5 seconds before the command "go". Upon giving the command "go" the tester pressed the event-marker switch. The event-marker switch was pressed again when the subject was observed to place the cup down on the table and when the subject was assessed to have finished the task. To ensure that a period of quiet sitting was recorded following the movement, data collection continued for approximately 5 seconds after the movement had been assessed to finish. The position of the cup was marked and the distance measured at the end of the testing.

6. Reaching across to the opposite side

The subject was instructed to repeat the previous movement, but reaching in the opposite direction. It was explained to the subject that the same "reaching" arm was to be used and that the movement would involve "twisting around and reaching across in the opposite direction". If a subject requested clarification the instructions were repeated and they were informed to do the movement "as you would naturally".

As in the test of reaching to the same side, data collection started approximately 5 seconds prior to the command "go"; the event-marker switch was pressed on the command "go", when the subject placed the cup on the table and when the subject was observed to finish the movement. Data collection continued for approximately 5 seconds after the movement was observed to stop. The position of the cup was marked and later the distance was measured.

Tests of reaching to the same side and reaching across to the opposite side were repeated until the subject had completed 3 reaches to either side.

9.1.2 Testing: hemiplegic subjects

Testing took place immediately before the subject attended for their normal daily physiotherapy treatment. Testing was carried out within the physiotherapy gym. The testing area was screened off from the rest of the gym to prevent distractions.

Pre-study trials of the testing protocol with individual patients with recently acquired stroke, at the Western General Hospital, Edinburgh, demonstrated that many of these patients were unable to rise to stand, stand or sit down without assistance. Subjects who had regained the ability to rise to stand, stand and sit down without assistance required supervision, and were often unable to maintain the standing posture for more than approximately 10 seconds. Some subjects at this stage in their recovery experienced levels of fatigue after carrying out one repetition of rising to stand, standing, or sitting down and were not be able to carry these out on a second or third attempt. A number of patients achieved the ability to stand independently prior to the ability to rise to stand or sit down. Subsequently the sequence of testing and testing protocol had to be adapted for the hemiplegic subjects. The sequence of testing is illustrated in Figure 9.2.

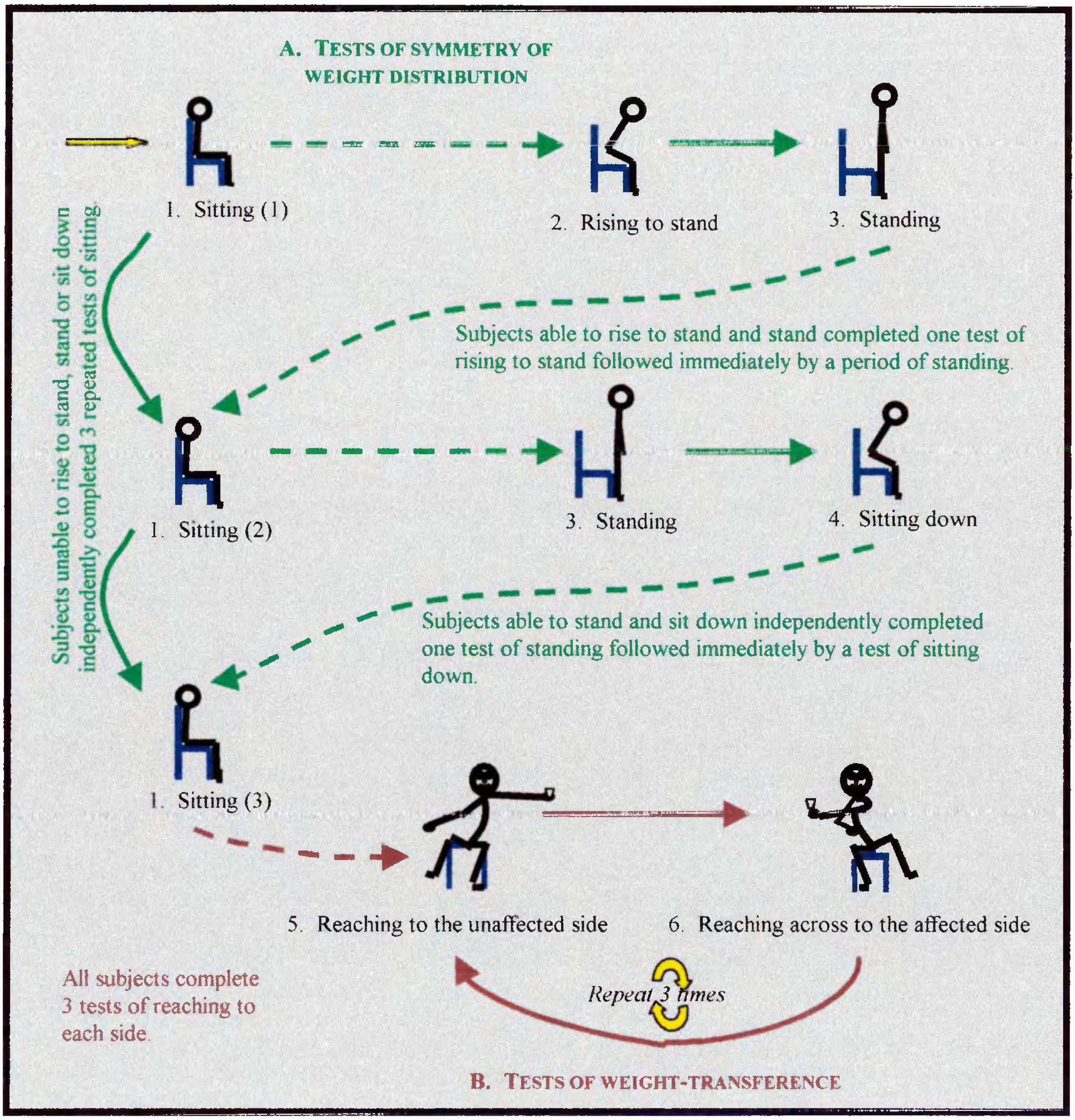


Figure 9.2 Sequence of testing for hemiplegic subjects.

As illustrated in Figure 9.2, the sequence of testing for the hemiplegic subjects was dependent on each subject's ability.

A.) Tests of symmetry of weight distribution: hemiplegic subjects

1. Sitting.

All subjects with hemiplegia completed 3 tests of sitting. The testing protocol was identical to that described for the healthy subjects, with the exception that the hemiplegic subjects were not requested to sit upright away from the backrest of the chair. During piloting of the testing protocol with patients with stroke it was observed that this command could result in excessive movement within the chair, excessive trunk flexion, pulling on the arms of the chair, or a failure to achieve the desired posture. To prevent this occurring the command given to the hemiplegic subjects was "sit upright", with no reference to the backrest of the chair.

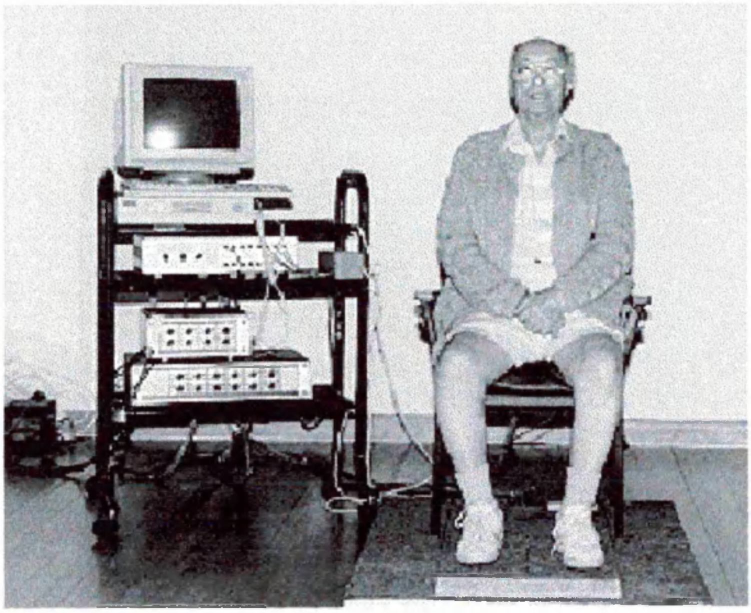


Figure 9.3 Test of sitting. Subject with right hemiplegia.

2. Rising to stand

Following the first test of sitting, all hemiplegic subjects were asked to attempt to stand up independently. Instructions given were the same as for the healthy subjects, with the addition of a statement telling the subject that, although the movement should be attempted alone, someone would be close to give assistance if necessary. If the subject could not achieve the task the testing continued with the second test of sitting. If the subject achieved the task, data collection was undertaken as for the healthy subjects. However, rather than stop the data collection after 5 seconds of quiet stance, data collection continued for approximately 10 seconds. Recording stance immediately after the end of rising to stand prevented the subject having to remain standing while the computer was prepared for a separate period of data collection. The subject sat down immediately following this data collection, as it was found that it was unsafe for patients to remain standing while the computer was prepared for the collection of data during sitting down.

3. ***Standing***

Tests of standing were incorporated into the tests of rising to stand and sitting down. Subjects successfully completing a test of rising to stand and a test of sitting down had two sets of data for stance, each recorded over a period of approximately 10 seconds. If a patient had achieved the routinely assessed goal of "10 seconds of independent stance" (assessed by the physiotherapist treating the patient) but was unable to independently rise to stand, then the subject was assisted into stance and one test of stance recorded. The testing protocol was the same as for the healthy subjects.

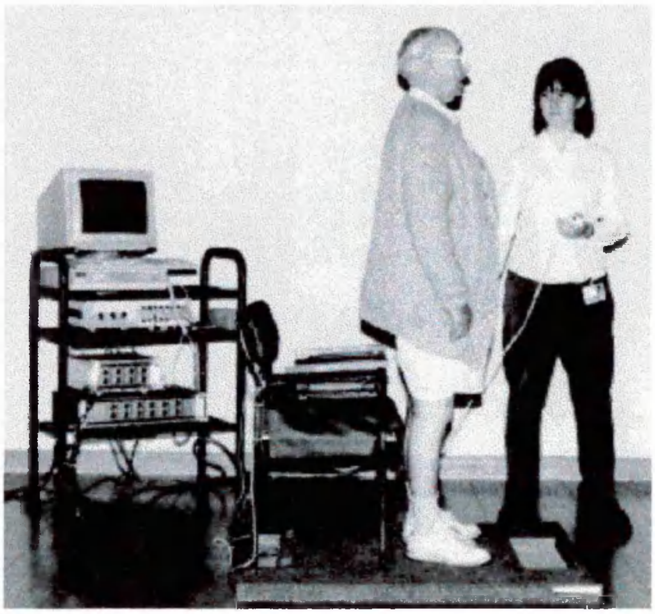


Figure 9.4 Test of standing. Subject with right hemiplegia. Tester standing beside subject to ensure safety.

4. ***Sitting down***

If the subject had achieved rising to stand independently, following the second test of sitting the subject was assisted to stand up. Instructions given were the same as for the healthy subjects, with the addition of a statement telling the subject that, although the movement should be attempted alone, someone would be close to give assistance if necessary. The testing protocol was the same as for the healthy subjects, with the exception that a period of 10 seconds of stance was collected prior to the command to sit down. This enabled 2 periods of 10 seconds of stance (one following rising to stand and one prior to sitting down) to be recorded and analysed.

This testing protocol resulted in each hemiplegic subject completing 3 tests of sitting. Single tests of rising to stand and sitting down were recorded according to each subject's ability. A maximum of 2 periods of 10 seconds of stance was recorded. Although there were differences in the standardised testing protocol and sequence used for the healthy and for the hemiplegic subjects, these differences were unavoidable due to the functional ability of the patients. The testing protocol and sequence for the hemiplegic subjects was kept as similar as possible to that of the healthy subjects, within the constraints of the ability of the hemiplegic subjects.

B.) Tests of weight-transference in sitting: hemiplegic subjects

All hemiplegic subjects were instructed to use their unaffected arm as their "reaching" arm. The sequence of tests was identical for the hemiplegic subjects and for the healthy subjects.

5. ***Reaching to the same side***

The testing protocol for the hemiplegic subjects was identical to that of the healthy subjects (Figure 9.5).

6. ***Reaching across to the opposite side***

The testing protocol for the hemiplegic subjects was identical to that of the healthy subjects (Figure 9.6).

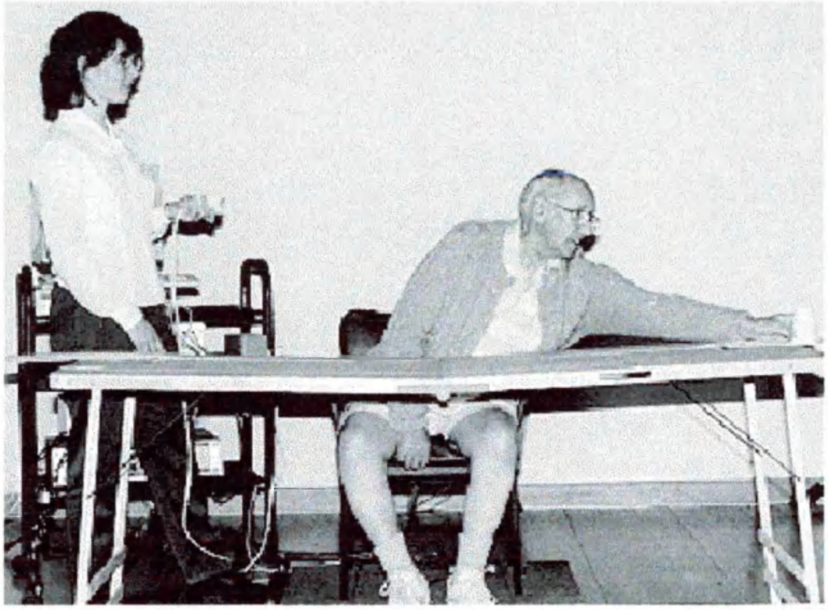


Figure 9.5 Test of reaching to the same side. Subject with right hemiplegia reaches out with the cup in the left (unaffected) hand, to the left (unaffected) side. The tester uses the handheld switch to mark events.

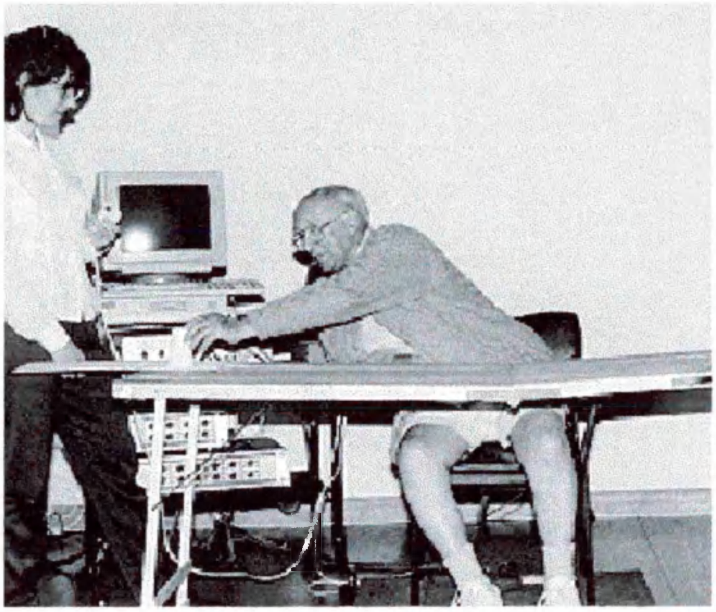


Figure 9.6 Test of reaching across to the opposite side. Subject with right hemiplegia reaches across with the cup in the left (unaffected) hand, to the right (affected) side. The tester uses the handheld switch to mark events.

9.2 Design of practice regime

9.2.1 Theoretical aims of practice regime

The practice regime was designed to meet the following criteria:

a) Aimed to improve sitting balance;

b) The regime could be carried out by a patient with recently acquired stroke under supervision only;

c) The regime would potentially be suitable for use in a number of different environments (hospital ward, home etc.);

d) The regime could be carried out without any risk to the patient;

e) The regime could be carried out within a one hour period, in order not to disrupt the daily routine of the hospital ward.

It was important that the evidence and knowledge pertaining to the optimal learning of motor tasks identified in the review of motor learning was incorporated into the developed regime of practice, in order to create an optimal practice effect.

Although a requisite of the practice regime was that it improve sitting balance, the lack of consistent definitions and terminology regarding balance made it essential to define more specific aims for the regime. Carr and Shepherd (1989a) stated that the maintenance of sitting balance:

> "requires the ability not just to stay there, but also to make small adjustments to the position as it is disrupted by movements of the head, the need for eye fixation and reaching out of the hand."

Thus sitting balance refers to the maintenance of a sitting posture and to movement within that posture. Symmetry of postural alignment and weight distribution has been proposed to be a variable relating to balance ability. Considering the knowledge related to balance, in conjunction with the literature pertaining to the problems with sitting balance following stroke, the specific aims of the regime for patients were defined as:-

1. To be able to achieve and maintain an appropriate symmetrical alignment in sitting.

2. To improve the ability to cope with the effects of gravity and therefore be able to make appropriate balance adjustments while shifting weight (in sitting).
3. To control body alignment during maximal voluntary shifts of the centre of pressure (in sitting).

Consequently, to meet these aims, practice had to consist of a series of tasks that required weight-shifting and the control of the movement of the centre of pressure, from a sitting position. Weight-shifting can be obtained through reaching movements with the non-affected arm. Since many patients with recently acquired stroke are unable to carry out controlled functional activities with their affected arm, the practice regime was developed so that it could be carried out entirely with the unaffected arm.

9.2.2 Timing and repetitions

The daily routine of the hospital ward, and the necessity for the practice regime not to disrupt the patients' attendance at other therapy interventions (physiotherapy, occupational therapy, speech therapy, psychology etc), necessitated that the practice regime be performed within a one hour period. The available resources dictated that one practice session could be supervised daily, Monday to Friday. There was no evidence pertaining to the optimal number of repetitions for learning: studies have used varied numbers of repetitions, although it is generally assumed that greater motor learning is related to a higher number of repetitions of a task. An attempt was made to develop a regime that included a maximal number of repetitions. This was assessed to be approximately 200 repetitions of varied reaching tasks. A requirement for rest periods between tasks to prevent fatigue was recognised: the length and frequency of rest periods were determined during the pilot study. It was envisaged that approximately 8-10 rests of 2 minutes would be required during the one-hour practice session. Thus it was envisaged that between 8 and 10 different tasks would be completed; with the parameters of distance reached, height reached, and angle of reach varied for each of these tasks. Each task was planned to be repeated between 20 and 30 times, in order to achieve the total of 200 repetitions. The different tasks were performed in a randomised order. During the development phase, the timing factors and parameters of task variation were investigated in a systematic manner in order to establish the practice regime for the clinical trial.

9.2.3 Development of the practice regime

In order to develop the regime of practice, with reference to the theoretically optimal parameters of practice and the aims of the independent practice identified previously, a series of practical investigations were necessary. All of these investigations were exploratory in nature and were carried out with a number of individual volunteers, who had a diagnosis of stroke and who were in-patients at the Western General Hospital. All of the investigative sessions were videotaped in order to allow further analysis. All of the volunteers gave verbal consent following an explanation of the purpose of the investigative session, and signed a consent form permitting the use of the video for the purposes of the research.

It was identified that the tasks should involve reaching with the unaffected arm in order to facilitate controlled movement of the COP of the seated subject within the BOS. Initial exploration identified a variety of potentially suitable reaching tasks, and determined that to ensure patient safety all tasks would have to be carried out upon a table in front of the subject. Exploration of the distance of reach of healthy subjects dictated the design and size of the table. The table top was designed to be placed on top of standard physiotherapy parallel bars in order to ensure that the equipment was portable and suitable for use within the restricted space available in the hospital environment. The table top was designed so that when placed on the parallel bars the subject could sit on a chair between the ends of the parallel bars with the front of the seat level with the front of the table, and with a 0.2m overlap on either side to ensure safety and a sense of security. The layout and dimensions of the chair and table are illustrated in Figure 9.7 - Figure 9.9.

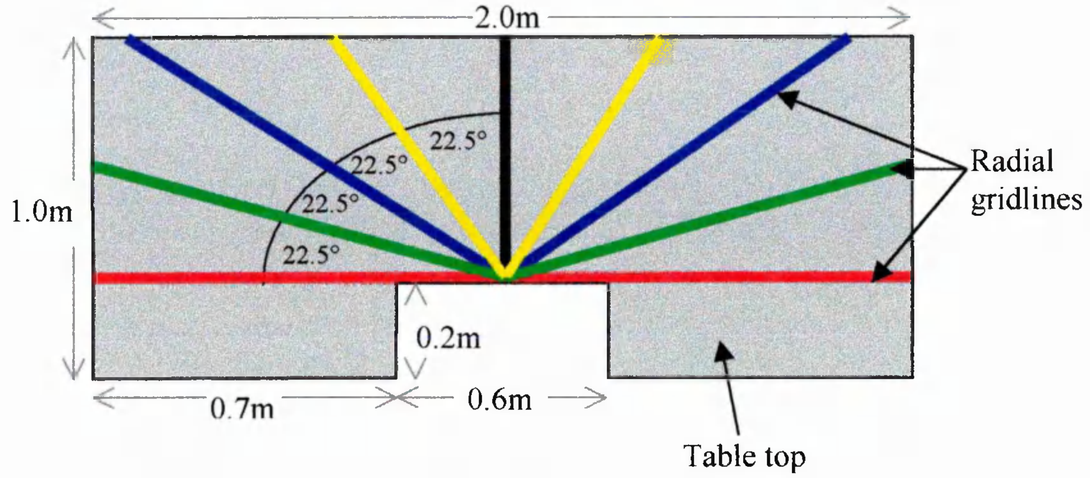


Figure 9.7 Dimensions of table top and layout of radial gridlines.

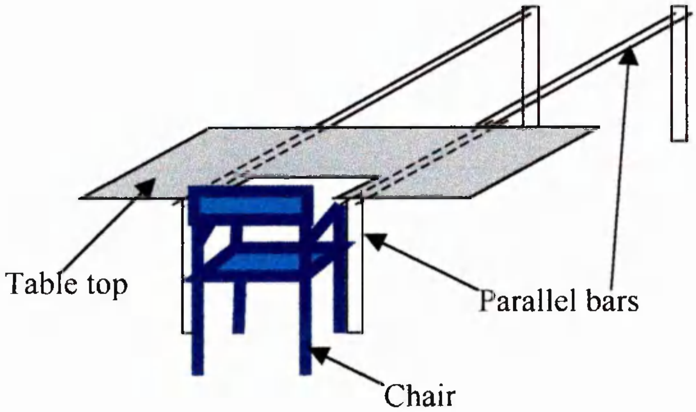
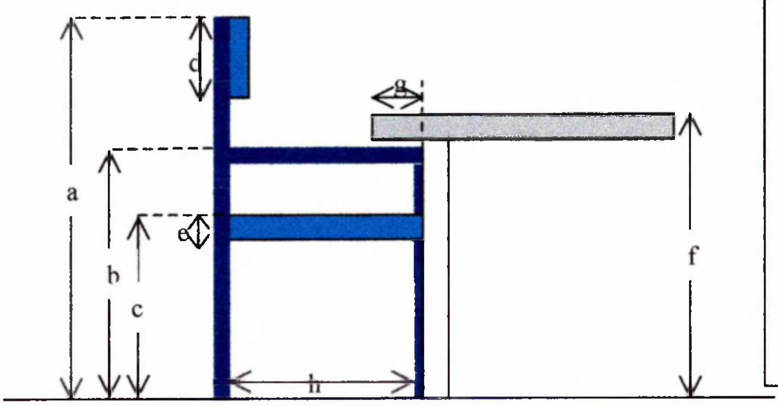


Figure 9.8 The table top was placed on the parallel bars, and the chair positioned between the front of the bars.



a – height to top of backrest from floor = 0.89m
b – height to top of armrest from floor = 0.63m
c – height to top of seat from floor = 0.46m
d – height of backrest = 0.17m
e – depth of cushion on seat = 0.04m
f – height to top of table from floor =0.78m
g – overlap of table over front of chair (on either side of arm rests) = 0.20m
h – depth of seat = 0.42m
width of seat = 0.48m

Figure 9.9 Dimensions and layout of chair and table.

In order to ensure that the tasks had objective and apparent goals, the tasks all involved moving objects to and from specific targets on the table. A number of different tasks were initially identified as potentially meeting the criteria for the aims of the practice. These included the movement of beanbags, blocks and small objects around the table; the "stacking" of items such as cones; the "hooking" of objects onto hooks positioned on vertical poles. In addition to the lack of evidence in the literature pertaining to the type of reaching tasks that would facilitate controlled movement of a subject's COP, there was no information pertaining to other factors and variations of reaching tasks. A number of key factors requiring clarification were identified and systematically explored in a series of investigative sessions.

The investigative sessions addressed the following key issues pertaining to the development of the regime of practice:-

- Parameters of height, angle and distance of reach;
- Effects of reaching across the midline, from the midline and to the midline;
- Effects of repetitive movements;
- Use of different reaching tasks;
- Type of seating;
- Effects of targeting and scoring on motivation and achievement;

Details of the specific aims, methodology and results of the investigative sessions are provided in Appendix C. Analysis of the investigative sessions led to the following conclusions:-

- Tasks must discourage subjects leaning through the table with their reaching arm, as this was observed to alter the postural control used during the activity. The amount of shoulder girdle activity appeared to increase when subjects leant through the table.
- Repeated tasks at the same angle increased postural asymmetry. If the subject did not have to cross the midline between tasks, frequently this was observed to result in a lack of trunk movement and reliance on upper limb movement to achieve the task. Figure 9.10 and Figure 9.11 illustrate the same task being repeated either side of the

midline. The subject had to move through the midline between these two repetitions of reaching.

- Use of a 'radial gridline' set-up (Figure 9.7) provided a good visual representation of the midline and provided a simple method of directing a subject's angle of reach.
- Reaching high prevented leaning through table and encouraged trunk extension (e.g. Figure 9.13 - Figure 9.15).
- Reaching high appeared to require greater postural control, necessitating increased control over trunk movement.
- Hooks and rings (Figure 9.14), stepped blocks (Figure 9.15) and stacking tasks (Figure 9.16) were all suitable for obtaining controlled, maintained reaching, without leaning through the table.
- A standard upright chair with armrests provided the most suitable seating for the regime. Wheelchairs encouraged trunk flexion and reduced the ability to achieve reaching tasks. Plinths resulted in subjects falling and requiring assistance to regain a sitting posture, and reduced subjects' sense of security and willingness to reach greater distances.
- A scoring system should be incorporated into the regime to provide quantitative feedback and improve motivation. Provision of scores and numerical targets increased the distance of reach and number of repetitions carried out by subjects.

Based on the conclusions from the development sessions, a practice regime incorporating 10 varied reaching tasks, aimed at improving sitting balance was developed. The repetitions of the varied reaching tasks resulted in a maximum number of repetitions of 203, thus meeting the aim of a regime of at least 200 repetitions. The tasks, movements required and number of repetitions are outlined in Table 9.1 and Appendix D, and are illustrated in Figure 9.10 - Figure 9.16. The tasks involved moving a series of items to "construct" a series of vertical poles, with pegs and rings, and the use of stepped blocks and stacking tasks. The objects to be moved were coloured red, green, blue or yellow and matched the colours of the radial gridlines. The cubes, poles and pegs were shaped either round or square. The use of different colours and shapes allowed careful control over the order of the tasks and the angle of reach without the necessity for complicated explanations. Simple instruction boards were made up to ensure that the tasks could be carried out independently (Appendix E). A scoring system was developed in association with the tasks (Appendix F). The developed regime was successfully piloted with a number of volunteers (patients with stroke from the stroke unit at the Western General Hospital). The practice regime took less than an hour for patients to carry it out. The required equipment was manufactured at Queen Margaret College. This developed regime of independent practice was implemented within the randomised controlled trial (section 7.1).

TASK	MOVEMENT	no.	total
1. Cubes out	Reach out and move cube ($10cm^3$) as far as possible along each of 8 radial gridlines. **(Figure 9.10 and Figure 9.11)**	8	8
2. Poles in	Reach out and place a pole into each of the cubes. **(Figure 9.12)**	8	16
3. Pegs in	Reach up and place a peg into a hole in each of the poles. Repeat. **(Figure 9.13)**	16	32
4. Hoops on	Reach up and place a hoop over each of the pegs. **(Figure 9.14)**	16	48
5. Hoops off	Reach up and remove each hoop.	16	64
7. Hoopla	Move 5 hoops across from one pole to the next. Repeat through sequence.	35	109
6. Pegs out	Reach up and remove each peg.	16	125
8. Poles out	Reach out and remove each pole.	8	133
9. Coins on step	Reach up and place £1 coins on highest left-hand step, and 50p coins on highest right-hand step. **(Figure 9.15)**	30	163
10.Stacking cones	Reach out and stack 5 cones along each radial gridline. **(Figure 9.16)**	40	203

Table 9.1 Tasks, movements and number of repetitions in developed practice regime.

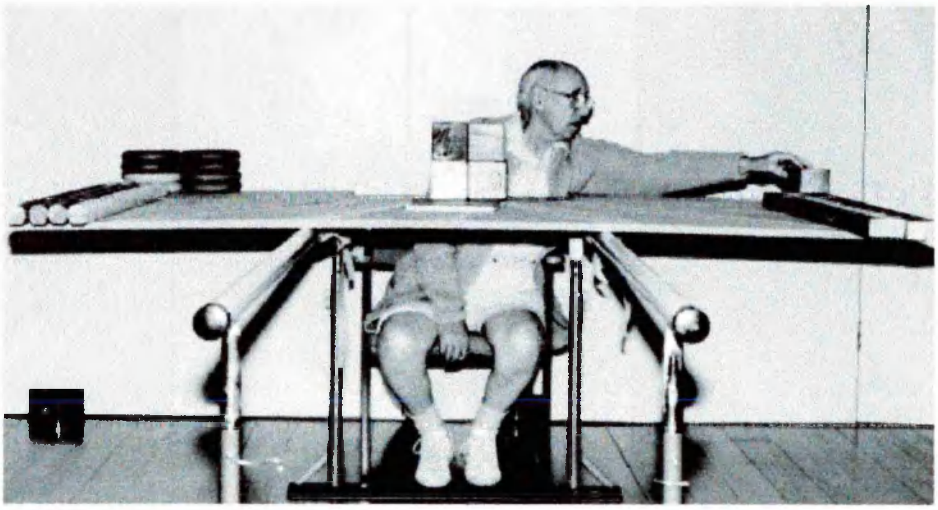


Figure 9.10 Task one. Cubes out. Subject with left hemiplegia reaching to the unaffected side.

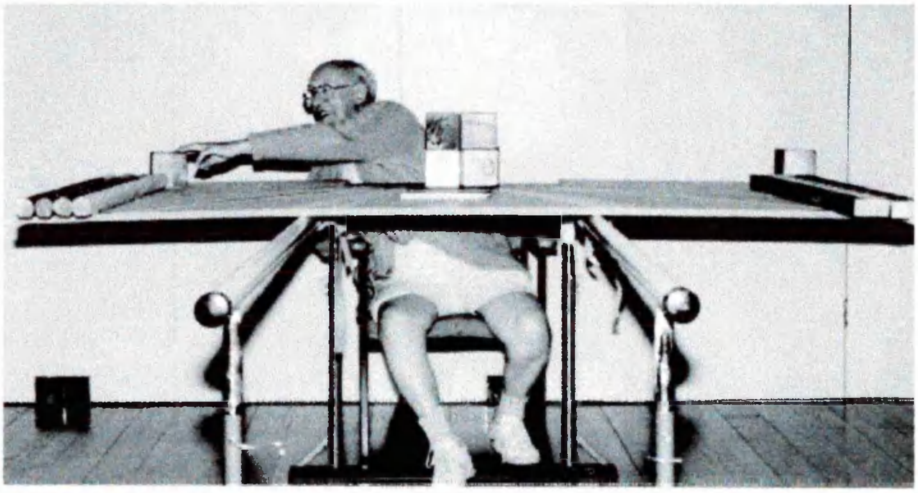


Figure 9.11 Task one. Cubes out. Subject with left hemiplegia reaching to the affected side.

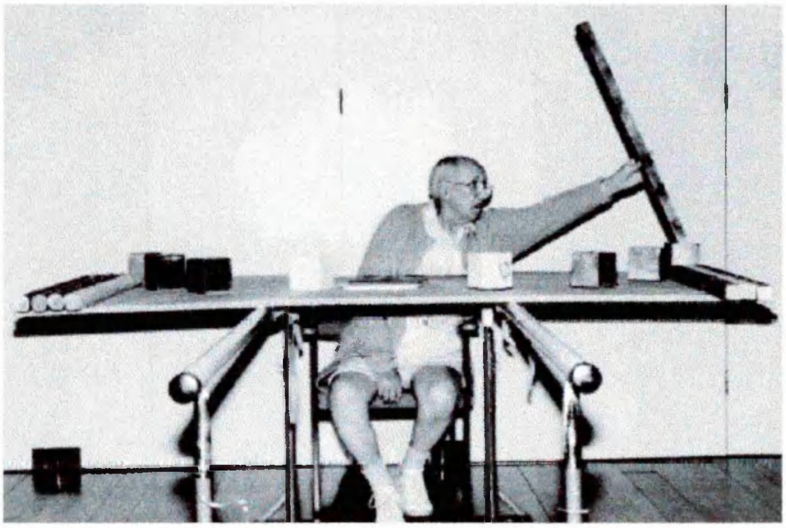


Figure 9.12 Task two. Poles in. Subject with right hemiplegia reaching to the unaffected side.

Figure 9.13 Task three. Pegs in. Subject with right hemiplegia reaching to the unaffected side.

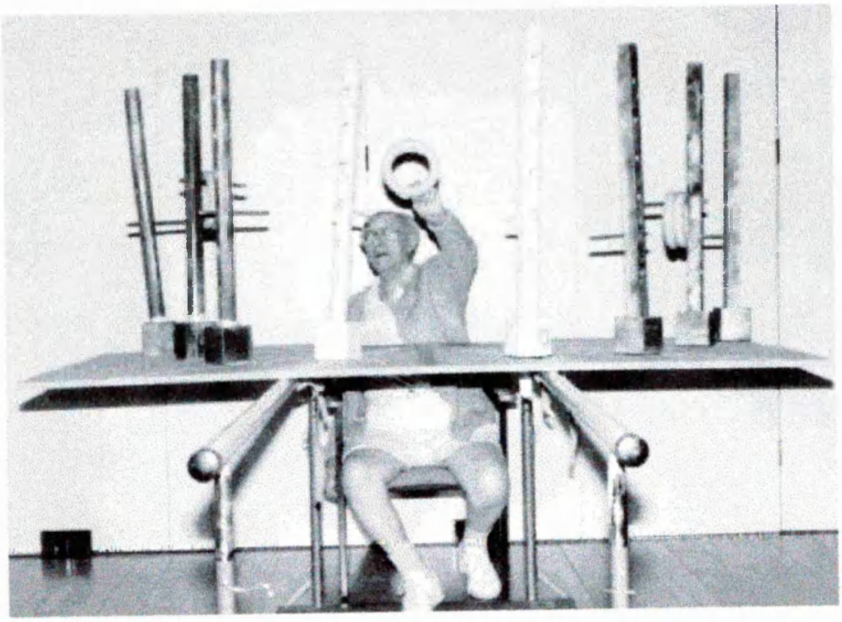


Figure 9.14 Task four. Hoops on. Subject with right hemiplegia starting to reach to the affected side.

Figure 9.15 Task nine. Coins on step. Subject with right hemiplegia reaching to the unaffected side.

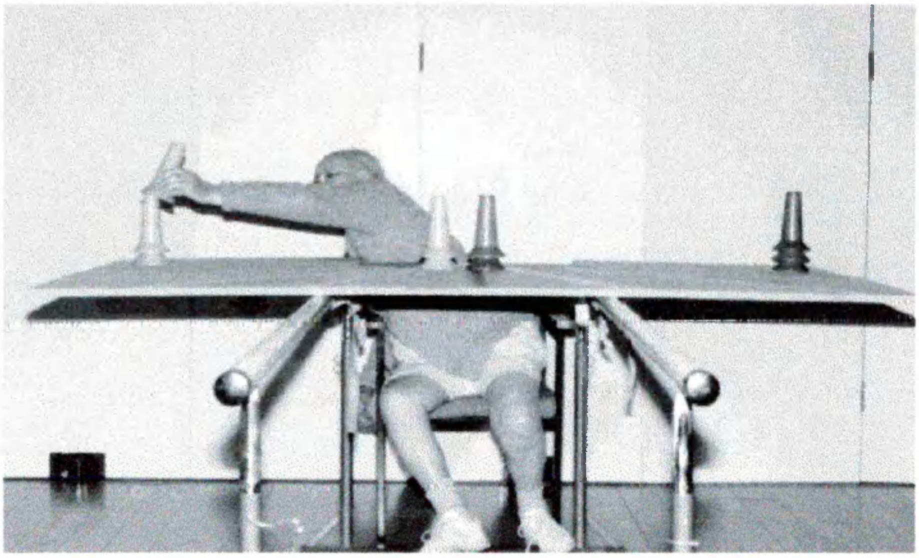


Figure 9.16 Task ten. Stacking cones. Subject with right hemiplegia reaching to the affected side.

10. Results: Subjects

10.1 Healthy group characteristics

In the young subject group there were 11 females and 9 males. In the elderly subject group there were 14 females and 6 males. Blocked randomisation was carried out to designate reaching arm – 10 of the young and 10 of the elderly subjects reached with their left arm, and 10 of the young and 10 of the elderly reached with their right arm.

Table 10.1 provides the age, height, mass and lower leg length profiles of the subjects. There was little difference in the height, mass and lower leg length of the young and elderly subjects. Details of the individual healthy subjects are displayed in Appendix I.

	Healthy - young	Healthy - elderly	Patients
mean age **age range**	22.7 ± 3.1 years 10 years	69.7 ± 4.3 years 19 years	69.9±12.46 years 49 years
mean height **height range**	1.7 ± 0.09 m 0.36m	1.7 ± 0.07 m 0.24m	1.6±0.11 m 0.47m
mean mass **mass range**	67.2 ± 10.4 kg 39.6kg	67.6 ± 9.3kg 30.9kg	56.0±10.3kg 44.6kg
mean LL length **range LL length**	0.49 ± 0.04 m 0.15m	0.47 ± 0.03 m 0.11m	0.45±0.04 m 0.20m

Table 10.1 Characteristics of healthy subjects and patients.

10.2 Patient group characteristics

28 hemiplegic subjects, 16 females and 12 males, were recruited for the clinical trial. Details of the individual patient characteristics are provided in Appendix J. 17 subjects had left hemiplegia; 11 had right hemiplegia. The age, height, mass and lower leg length profiles of the hemiplegic subjects are shown in Table 10.1. The mean age of the hemiplegic subjects was similar to the mean age of the elderly healthy subjects, although the age range of the hemiplegic subjects was larger than that of the elderly healthy subjects. The height, mass and lower leg lengths of the hemiplegic subjects was similar to that of the young and elderly healthy subjects.

10.2.1 Control and practice group characteristics

Blocked randomisation was used to assign the hemiplegic subjects to the control or practice group, with a ratio of 2:1. 19 (68%) of the hemiplegic subjects were assigned to the control group; 9 (32%) were assigned to the practice group. The mean age of subjects in the control group was 68.4±13.4 years. The mean age of subjects in the practice group was 73.1±10.3 years. The profile of the control and practice groups at entry into the trial is detailed in Table 10.2. The proportion of patients with different stroke classifications in the control and practice group was similar, although the practice group contained slightly less TACIs, and a greater proportion of PACIs and LACIs, than the control group. While the control group contained a very small proportion of subjects with POCIs and PICHs, the practice group contained no subjects with these stroke classifications. The proportion of subjects with left and right hemiplegia was relatively even in the control group, while in the practice group there was a greater proportion of left hemiplegics. Although there were slight differences in the proportion of control and practice group subjects with different stroke-related characteristics and in the proportion in difference age groups, these differences were relatively small. However, there was a disproportionate ratio of males to females in the two groups, with – by chance – the entire practice group being female.

	Control group	Practice group
Number of subjects	19 (100%)	9 (100%)
Number of TACIs	6 (32%)	2 (22%)
Number of PACIs	3 (16%)	3 (33%)
Number of LACIs	5 (26%)	4 (44%)
Number of POCIs	2 (11%)	0 (0%)
Number of PICHs	3 (16%)	0 (0%)
Number of left hemiplegics	10 (53%)	7 (78%)
Number of right hemiplegics	9 (47%)	2 (22%)
Number of males	12 (63%)	0 (0%)
Number of females	7 (37%)	9 (100%)
Number aged under 65 years	6 (32%)	1 (11%)
Number aged 65-80 years	9 (47%)	5 (56%)
Number aged over 80 years	4 (21%)	3 (33%)

Table 10.2 Patient characteristics at entry into clinical trial

The Barthel index for each of the control and practice group subjects at entry into the clinical trial is displayed in Figure 10.1. The range of Barthel scores was 10 for the control group and 13 for the practice group. The median value for the control group was lower than the median for the practice group, being 5 and 8 respectively. These values indicate that the control group subjects generally had lower Barthel scores at entry into the trial.

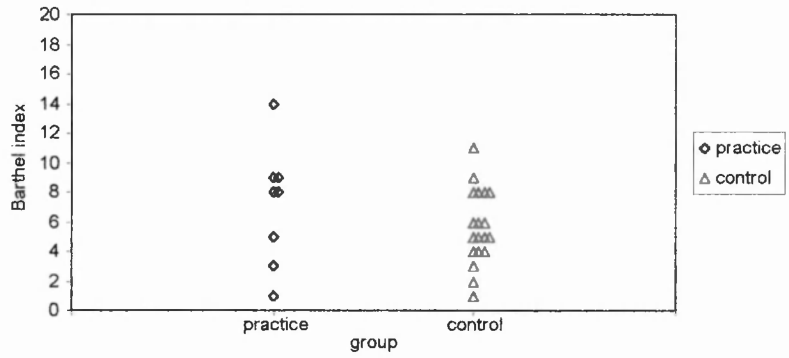


Figure 10.1 Barthel index at entry into trial (week 0).

10.3 Patient profiles over test weeks

10.3.1 Control and practice group characteristics over test weeks

Table 10.3 and Table 10.4 display the number and percentage of subjects with different characteristics assigned to each group (week 0) and the number and percentage of subjects included during subsequent test weeks (weeks 1-6).

The decrease in subject numbers over the test weeks was due to patients being discharged from the trial; either due to discharge from the hospital, or for other reasons (Figure 10.2 and Figure 10.3). 9 of the control group subjects were discharged before 7 weeks of testing were completed: of these subjects 6 were discharged from the hospital, 1 self-discharged from the hospital, 1 died and 1 developed a chest infection and was unable to attend physiotherapy. 4 of the practice group subjects were discharged before 7 weeks of testing were completed: 2 of these subjects were discharged from the hospital, 1 subject refused to have objective measurements taken and 1 subject fell on the ward and received a fractured neck of femur. Details of these patients and the timing of the discharges are provided in Appendix J.

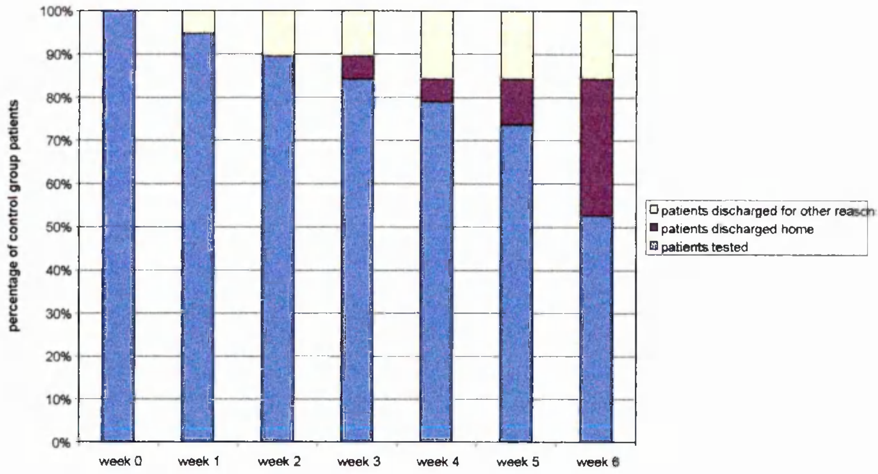


Figure 10.2 Patient discharges over test weeks. Control group.

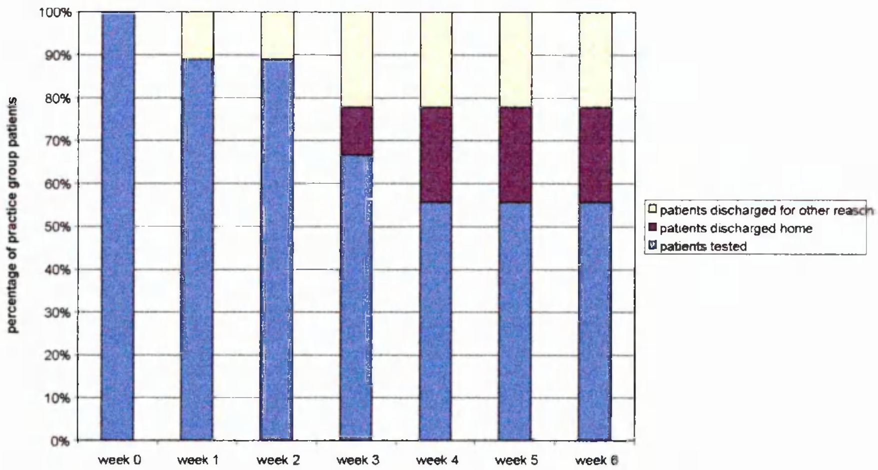


Figure 10.3 Patient discharges over test weeks. Practice group.

The proportion of subjects discharged from the control and practice group was similar, with 47% of the control group subjects and 44% of the practice group subjects discharged. However, the rate of discharge from the practice group was greater up until week 4. No discharges were made from the practice group after week 3. The proportion of subjects with different stroke classifications, side of hemiplegia and age groups remained similar in the practice and control groups over the test weeks (Table 10.3 and Table 10.4).

	week 0	week 1	week 2	week 3	week 4	week 5	week 6
Number in control group	19 (100%)	18 (100%)	17 (100%)	16 (100%)	15 (100%)	14 (100%)	10 (100%)
Number of TACIs	6 (32%)	5 (28%)	5 (29%)	5 (31%)	5 (33%)	5 (36%)	4 (40%)
Number of PACIs	3 (16%)	3 (17%)	3 (18%)	2 (13%)	1 (7%)	1 (7%)	0 (0%)
Number of LACIs	5 (26%)	5 (28%)	4 (24%)	4 (25%)	4 (27%)	4 (29%)	3 (30%)
Number of POCIs	2 (11%)	2 (11%)	2 (12%)	2 (13%)	2 (13%)	1 (7%)	0 (0%)
Number of PICHs	3 (16%)	3 (17%)	3 (18%)	3 (19%)	3 (20%)	3 (21%)	3 (30%)
Number of left hemiplegics	10 (53%)	9 (50%)	8 (47%)	8 (50%)	7 (47%)	7 (50%)	7 (70%)
Number of right hemiplegics	9 (47%)	9 (50%)	9 (53%)	8 (50%)	8 (53%)	7 (50%)	3 (30%)
Number of males	12 (63%)	12 (67%)	11 (65%)	10 (62%)	9 (60%)	9 (64%)	7 (70%)
Number of females	7 (37%)	6 (33%)	6 (35%)	6 (38%)	6 (40%)	5 (36%)	3 (30%)
Number aged under 65 years	6 (32%)	6 (33%)	6 (35%)	6 (38%)	6 (40%)	5 (36%)	2 (20%)
Number aged 65-80 years	9 (47%)	8 (44%)	8 (47%)	7 (44%)	6 (40%)	6 (43%)	6 (60%)
Number aged over 80 years	4 (21%)	4 (22%)	3 (18%)	3 (19%)	3 (20%)	3 (21%)	2 (20%)

Table 10.3 Number of patients in control group and their characteristics (percentage of control group with each characteristic each week).

	week 0	week 1	week 2	week 3	week 4	week 5	week 6
Number in practice group	9 (100%)	8 (100%)	8 (100%)	6 (100%)	5 (100%)	5 (100%)	5 (100%)
Number of TACIs	2 (22%)	1 (13%)	1 (13%)	1 (17%)	1 (20%)	1 (20%)	1 (20%)
Number of PACIs	3 (33%)	3 (38%)	3 (38%)	1 (17%)	1 (20%)	1 (20%)	1 (20%)
Number of LACIs	4 (44%)	4 (50%)	4 (50%)	4 (67%)	3 (60%)	3 (60%)	3 (60%)
Number of POCIs	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
Number of PICHs	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
Number of left hemiplegics	7 (78%)	7 (88%)	7 (88%)	5 (83%)	4 (80%)	4 (80%)	4 (80%)
Number of right hemiplegics	2 (22%)	1 (13%)	1 (13%)	1 (17%)	1 (20%)	1 (20%)	1 (20%)
Number of males	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
Number of females	9 (100%)	8 (100%)	8 (100%)	6 (100%)	5 (100%)	5 (100%)	5 (100%)
Number aged under 65 years	1 (11%)	1 (13%)	1 (13%)	1 (17%)	1 (20%)	1 (20%)	1 (20%)
Number aged 65-80 years	5 (56%)	5 (63%)	5 (63%)	4 (67%)	3 (60%)	3 (60%)	3 (60%)
Number aged over 80 years	3 (33%)	2 (25%)	2 (25%)	1 (17%)	1 (20%)	1 (20%)	1 (20%)

Table 10.4 Number of patients in practice group and their characteristics (percentage of practice group with each characteristic each week).

10.3.2 Measurements completed by patients over test weeks

All subjects included in the trial at each test week completed tests of quiet sitting and reaching from sitting. Not all subjects were able to complete tests of standing, rising to stand and sitting down at each test week. The number of test results for these functions varied over the test weeks, as a result of inability to perform the task and patient discharge from the trial (Figure 10.4 - Figure 10.8).

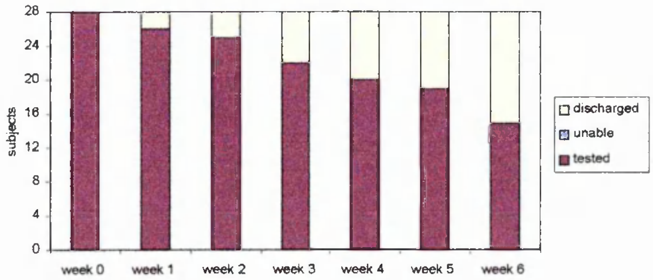


Figure 10.4 Total number of subjects completing tests of sitting over test weeks.

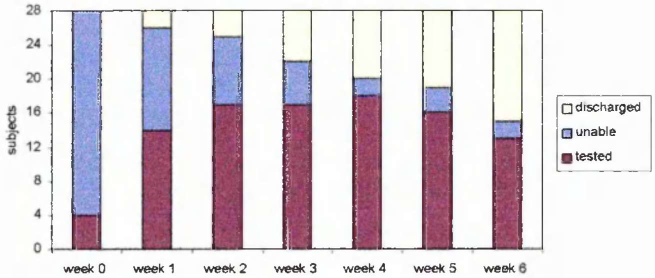


Figure 10.5 Total number of subjects completing tests of standing over test weeks.

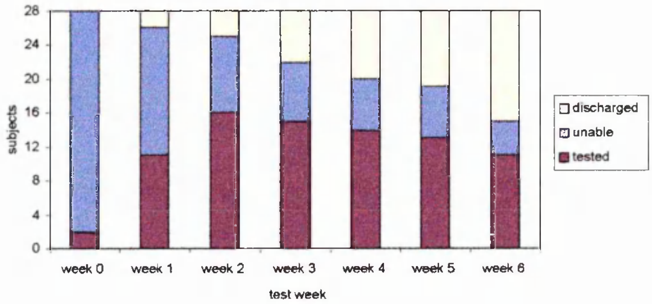


Figure 10.6 Total number of subjects completing tests of rising to stand over test weeks.

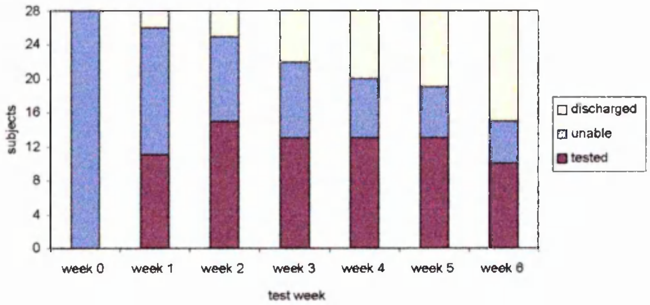


Figure 10.7 Total number of subjects completing tests of sitting down over test weeks.

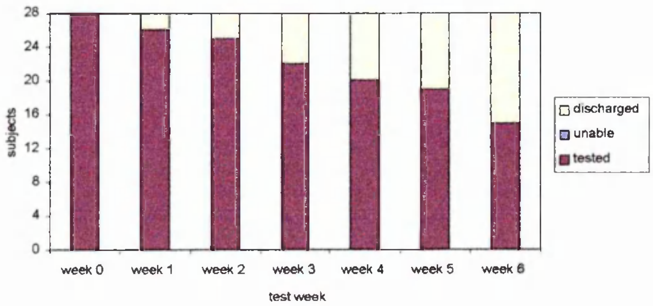


Figure 10.8 Total number of subjects completing tests of reaching over test weeks.

10.3.3 Functional scores over test weeks

Figure 10.9 and Figure 10.10 illustrate the Barthel scores for control and practice patients over the test weeks, with the classification of stroke indicated for each subject. Table 10.5 and Table 10.6 display the median and the range of Barthel scores and scores for the rising to stand section of the Motor Assessment Score. The Barthel and Motor Assessment scores both tended to increase over the test weeks.

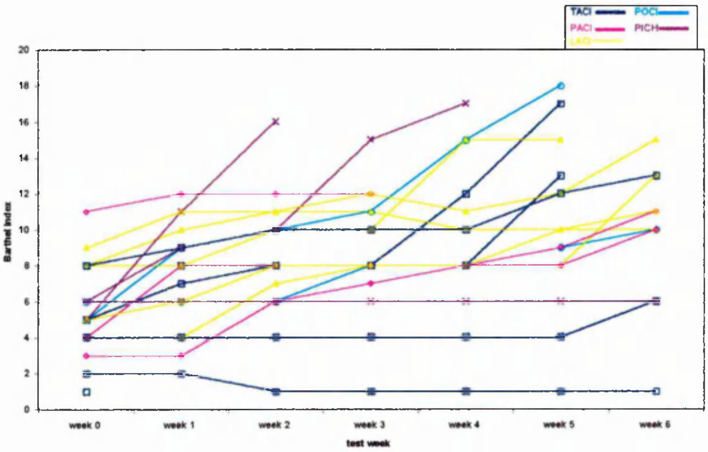


Figure 10.9 Barthel index over test weeks. Control group. Showing stroke classification.

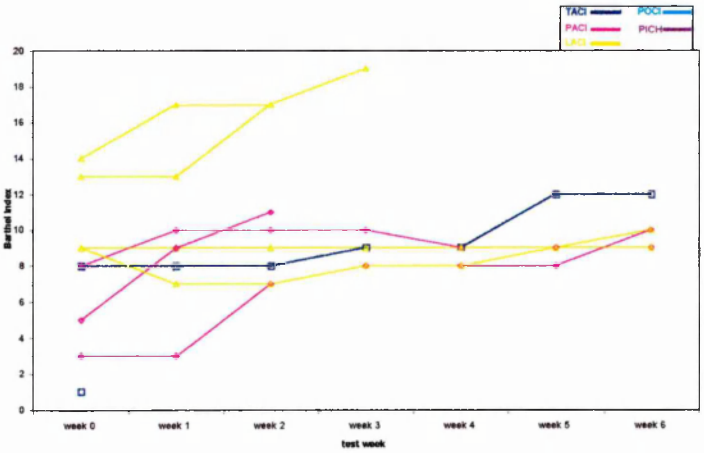


Figure 10.10 Barthel index over test weeks. Practice group. Showing stroke classification.

control	week 0	week 1	week 2	week 3	week 4	week 5	week 6
median	5	8	8	8	8	10	10
range	10	10	15	14	16	17	14
practice	week 0	week 1	week 2	week 3	week 4	week 5	week 6
median	8	9	9.5	9	9	9	10
range	13	14	10	11	1	4	3

Table 10.5 Median and range of scores for Barthel Index.

control	week 0	week 1	week 2	week 3	week 4	week 5	week 6
median	0	1	2	2	2.5	3	3
range	1	3	4	5	5	5	5
practice	week 0	week 1	week 2	week 3	week 4	week 5	week 6
median	0	1	1.5	2	1	2	3
range	1	4	4	5	4	4	4

Table 10.6 Median and range of scores for rising to stand section of Motor Assessment Score.

10.4 Profile of independent practice

9 subjects took part in the practice regime. 5 subjects attended for all 4 weeks of the regime; 3 for 3 weeks and 1 for 1 week. Of the 3 subjects attending for 3 weeks, 2 were discharged home and 1 was discharged following a fall on the ward resulting in a lower limb fracture. The subject who only completed 1 week was discharged from the trial after refusing to attend for the weekly measurements.

Not all of the subjects attended for all 5 practice sessions each week; reasons for non-attendance were refusal (generally due to tiredness), alternative appointments such as MRI scans and Occupational Therapy appointments, and the absence of the practice supervisor due to Bank holidays. Of the total possible number of test sessions, between 0% and 60% were missed, by each subject. The median percentage of possible sessions missed was 20%. The median percentage of possible sessions missed due to tiredness was 10% (range 0% to 60%), and the median percentage of possible sessions missed due to other reasons was 10% (range 0% to 17%). Figure 10.11 - Figure 10.14 display the attendance at the practice sessions over the 4 week period for each of the subjects. These graphs illustrate that the number of refusals to attend due to tiredness decreased over the 4 weeks. Only one subject (subject A) attended all 20 practice sessions over the 4 weeks.

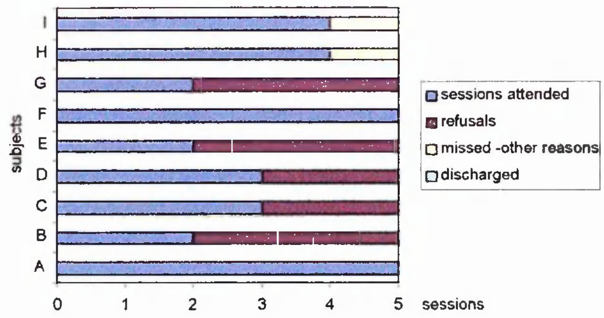


Figure 10.11 Attendance at practice sessions. Week 1.

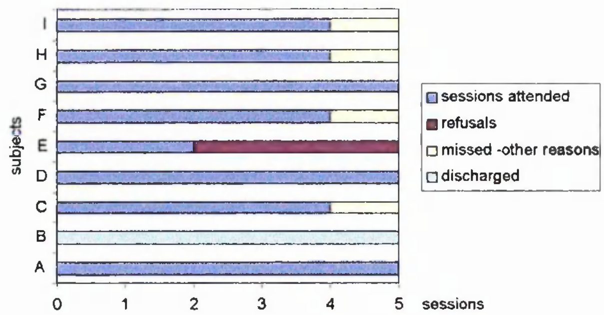


Figure 10.12 Attendance at practice sessions. Week 2.

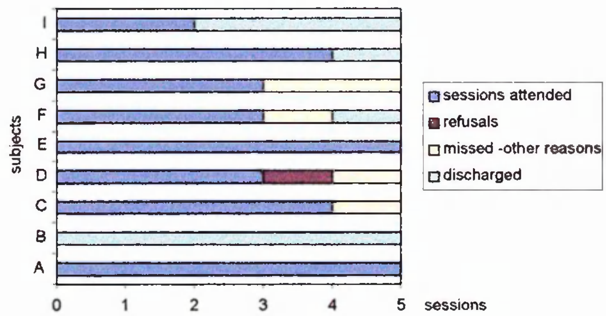


Figure 10.13 Attendance at practice sessions. Week 3.

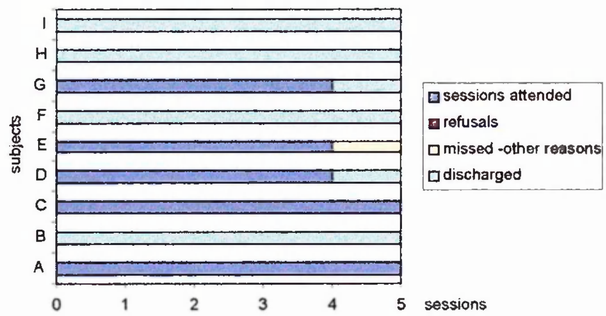


Figure 10.14 Attendance at practice sessions. Week 4.

The number of repetitions of reaching at each practice session varied between subjects and between day of attendance. The reason for this variation was subject tiredness resulting in a request to finish. The maximum possible number of repetitions per session was 203; giving a maximum of 1015 per week. Figure 10.15 illustrates the number of repetitions carried out each week by the subjects.

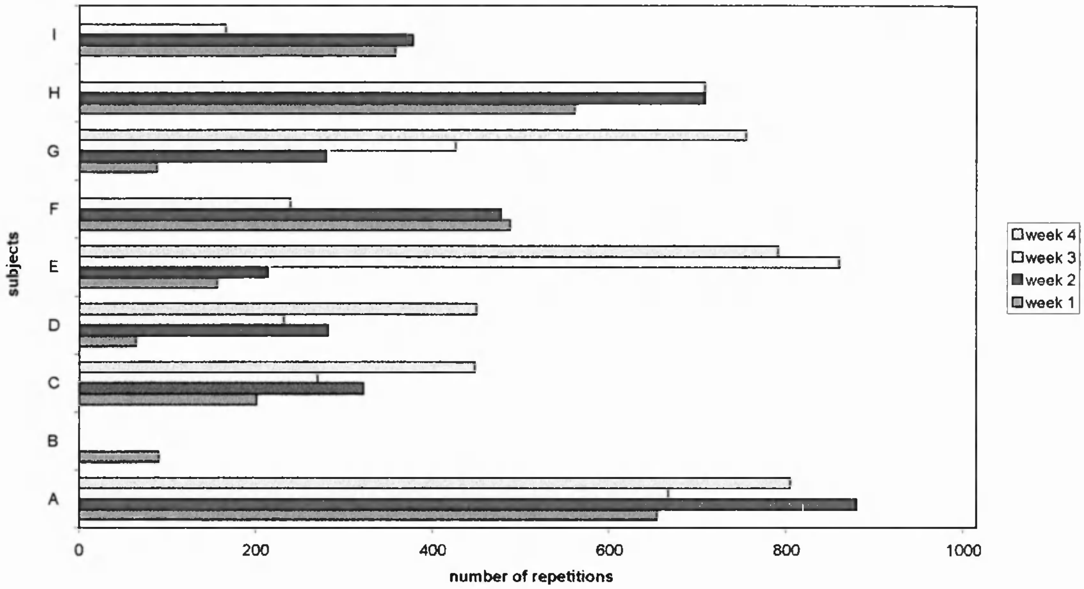


Figure 10.15 Total number of repetitions carried out during different practice weeks.

The distance and height of reach during the tasks involved in the practice regime varied, both inter-subject and intra-subject. The distance reached during practice Task 1, and the height reached during practice Task 3, for each of the subjects on each of the practice days attended is documented in Appendix L.

11. Results : Sitting

11.1 Raw data and analysis

The symmetry index, SI (see section 8.3), was determined for each 10 second test of sitting. Examples of the SI over the 10 seconds of data collection, as derived from the force data, for a young healthy, elderly healthy and hemiplegic subject are provided in Figure 11.1, Figure 11.2 and Figure 11.3.

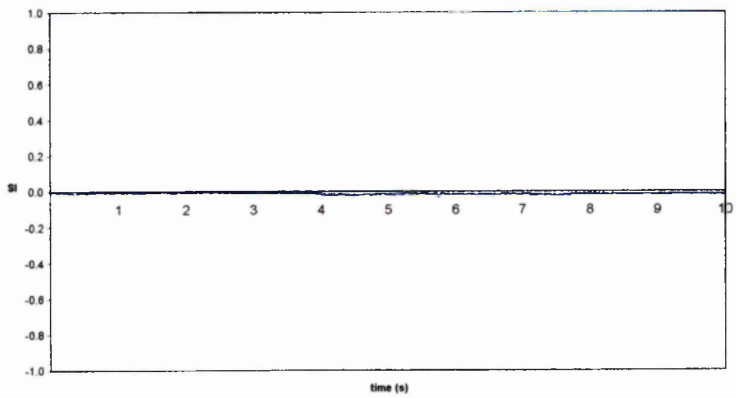


Figure 11.1 Symmetry of sitting. Young healthy subject.

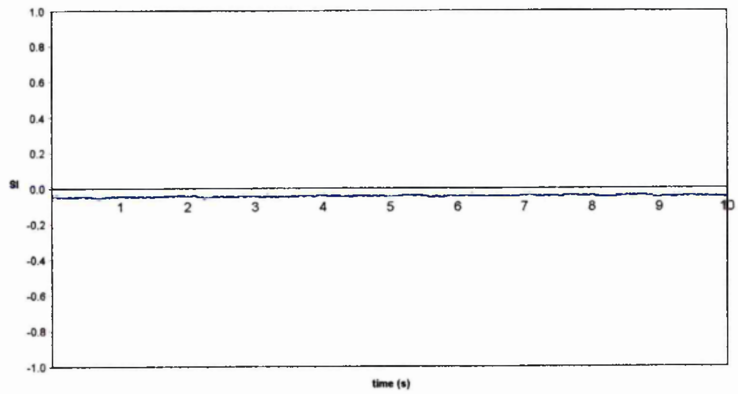


Figure 11.2 Symmetry of sitting. Elderly healthy subject.

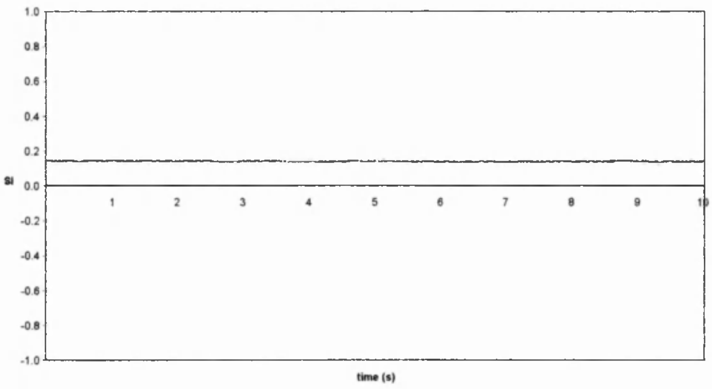


Figure 11.3 Symmetry of sitting. Hemiplegic subject.

The mean and maximum values of the standard deviation of the SI over the 10 seconds of data collection for the 20 young and 20 elderly healthy subjects, and for the initial measurement from the first 12 hemiplegic subjects are given in Table 11.1.

	young healthy	elderly healthy	hemiplegic
mean of standard deviations	0.008	0.007	0.006
maximum of standard deviations	0.014	0.016	0.030
mean range of SI	0.044	0.038	0.052
maximum range of SI	0.082	0.081	0.126

Table 11.1 Mean and maximum values of standard deviation and range of symmetry index during sitting (SI).

The standard deviation and range of the SI over 10 seconds of sitting was low for the young and elderly healthy subjects and for the hemiplegic subjects. During 10 seconds of sitting, the maximum standard deviation of the SI was 0.030 and the maximum range of the SI was 0.126 for the healthy and hemiplegic subjects. This lack of variation in the SI during sitting for both healthy and hemiplegic subjects indicated that the mean SI was an appropriate variable for use in the investigation of the symmetry of sitting. The mean SI over the 10 seconds of data for each measurement of sitting was determined for each subject.

11.2 Healthy subjects

The mean SI from the 3 trials of sitting for each of the healthy subjects is displayed in Figure 11.4 and Figure 11.5. These graphs demonstrate that there was little variation between the repeated values for individual subjects or for the group of subjects.

Calculating the mean of the 3 repeated values for each subject demonstrated that 90% of the mean values fell within a range of 0.10 for the young subjects and within a range of 0.16 for the elderly subjects.

The Intraclass Correlation Coefficient (ICC) is often calculated in order to assess the statistical significance of the difference between repeated trials. However when there is low variation between subjects the use of the ICC statistic is limited, and the ICC value will be low despite there being minimal differences between repeated measures (Chambers et al, 1992). In addition the use of the ICC is not robust to the effects of outliers in the results (Chambers et al, 1992). When there is little variation between subjects and the potential for outliers in the results, the calculation of the percentage close agreement (PCA) is more appropriate and robust (Chambers et al, 1992). The PCA is a measure of agreement, based on the distribution of the differences between repeated measurements. The magnitude of the difference between each of the repeated measures for an individual subject is determined, and from this the percentage of differences for the group of subjects falling within a certain magnitude of each other is calculated. Rather than defining the magnitude of the differences and determining the percentage of differences within that magnitude, the magnitude of the difference included by a certain percentage of the differences can be determined. Thus, in this case the difference between each of the 3 repeated measures for each healthy subject was determined. The values for the differences from each individual subject were combined and the magnitude of the difference within which specific percentages of the values fell was determined. Table 11.2 displays the magnitude of the difference between the repeated measures of mean SI within which 80%, 90%, 95% and 100% of the differences fell. The magnitude of the difference within which 100% of the differences fall is the same as the maximum difference between repeated measures for any of the individual subjects.

The variation between 3 repeated measures was low, with 90% of the young subjects having a difference of less than 0.08 and 90% of the elderly subjects having a difference of less than 0.14. The variation between the 3 repeated measures for each individual subject and the variation between the mean of the 3 repeated values for the group of subjects was similar, being 0.08 and 0.10 respectively for the young subjects, and 0.14 and 0.16 respectively for the elderly subjects. The similarity in the variation between the repeated measures and the variation between the group measures can be observed in Figure 11.4 and Figure 11.5. Use of single measures, rather than the mean value, may introduce errors related to the variation between repeated measures. The mean of the 3 repeated measures was therefore an appropriate outcome measure for each individual subject. The mean of the 3 repeated measures for the symmetry of weight distribution during sitting for each subject was therefore used in the remaining analysis.

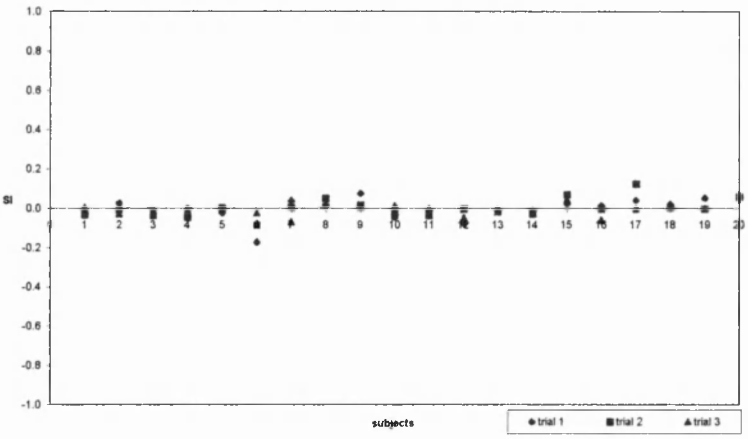


Figure 11.4 Mean symmetry index from 3 trials of sitting. Young healthy subjects.

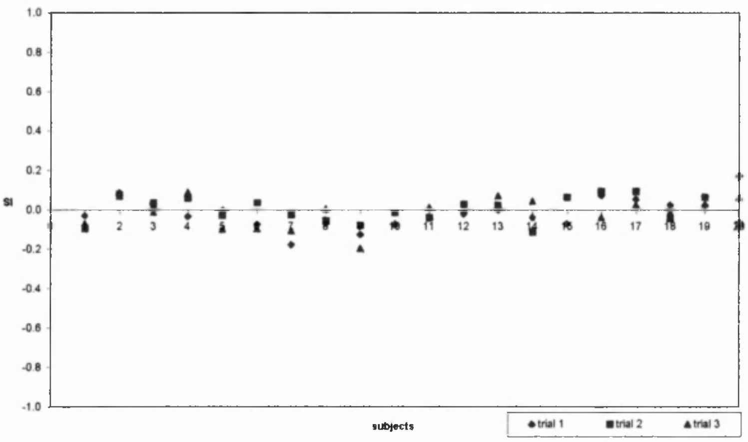


Figure 11.5 Mean symmetry index from 3 trials of sitting. Elderly healthy subjects.

	PCA (80%)	PCA (90%)	PCA (95%)	PCA (100%)
Young	0.06	0.08	0.09	0.15
Elderly	0.11	0.14	0.14	0.25

Table 11.2 PCA for 3 repeated trials of mean symmetry of sitting; young and elderly healthy subjects (SI).

Plotting the distribution of the mean SI for the young and elderly healthy subjects demonstrates that the groups of healthy subjects exhibited a normal distribution (Figure 11.6 and Figure 11.7). The median values and 5th, 25th, 75th and 95th percentiles for the young and elderly subjects are shown in Table 11.3. The median values were close to zero, demonstrating that the young and elderly subjects tended to have symmetrical weight distribution in sitting. The interquartile and 90% range of the mean SI were 0.04 and 0.10 respectively for the young subjects and 0.08 and 0.16 respectively for the elderly subjects, showing that there was little variation in the mean SI for the group of healthy subjects.

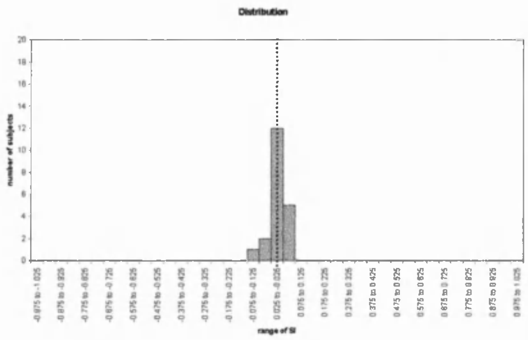


Figure 11.6 Distribution of mean symmetry index during sitting for young healthy subjects.

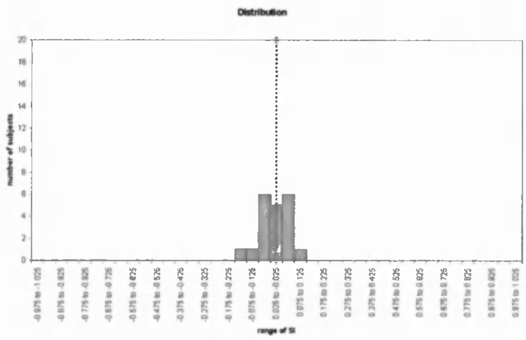


Figure 11.7 Distribution of mean symmetry index during sitting for elderly healthy subjects.

	young	elderly
median	-0.01	0.00
25th percentile	-0.02	-0.04
75th percentile	0.02	0.04
interquartile range	0.04	0.08
5th percentile	-0.05	-0.10
95th percentile	0.05	0.06
90% range	0.10	0.16

Table 11.3 Medians and percentiles for sitting. Young and elderly healthy subjects (SI).

To examine the association between the symmetry of weight distribution in sitting and the independent variables (age, age-group, gender, mass, height, lower-leg length and dominant hand) multiple regression was carried out. Multiple regression determines the regression equation, $Y = mX + c$, for the relationship between the dependent variable (Y) and the independent variable (X) (where m is the gradient of the line and c, the constant, is the intercept with the Y-axis). The R-squared value, the coefficient of determination, provides a representation of the percentage correlation between the dependent and independent variable. R-squared is a value from 0 to 1. In addition to the R-squared value, the statistical significance of the gradient (t_m) and the constant of the regression line (t_c) can be determined. For the purpose of this study, significant association was defined as occurring when there was greater than 10% association (R-squared > 0.1) and the significance of the gradient and constant was greater than 95% ($t_m < 0.05$ and $t_c < 0.05$). Table 11.4 illustrates the R-squared value and t_m and t_c, and the gradient and constant for the regression equations for which there was significant association between the dependent and independent variables.

independent variable	age	age group	gender	mass	height	lower leg length	dominant hand
R^2	0.007	0.004	0.190	0.009	0.046	0.037	0.050
t_m	0.616	0.709	0.005	0.558	0.182	0.236	0.168
t_c	0.905	0.897	0.089	0.496	0.171	0.218	0.257
gradient							
constant							

Table 11.4 R-squared and significance values for association between mean sitting SI and independent variables.

The R-squared value for the association between the mean sitting symmetry and gender indicates that there was a 19% association between these variables. The significant t value for the gradient (t_m) indicated that this was statistically significant; however t_c was not significant. There was therefore no significant association between the mean SI during sitting and any of the independent variables.

11.3 Hemiplegic subjects

11.3.1 Baseline measurement (week 0)

The mean of the 3 repeated measures of sitting symmetry on each test week was determined for each hemiplegic subject. The distribution of the mean SI from the baseline measure (week 0) for the hemiplegic subjects is shown in Figure 11.9. The distribution of the mean SI for the hemiplegic subjects can be compared with that from the healthy subjects: Figure 11.8 shows the distribution for the young and elderly healthy subjects combined. The distribution of the mean values from the hemiplegic subjects can be observed to be around 0. The median value for the hemiplegic subjects was –0.01. This was the same as the median value for the healthy subjects (young and elderly combined). In addition, these graphs demonstrate that there was greater variation between the hemiplegic subjects than there was between normal subjects. This observation was supported by the values of the interquartile and 90% range: the interquartile range was 0.06 for the healthy subjects and 0.13 for the hemiplegic subjects, and the 90% range was 0.15 for the healthy subjects and 0.34 for the hemiplegic subjects. Thus while there was no difference in the median values for the mean SI during sitting for the groups of healthy and hemiplegic subjects, there was a difference in the magnitude of the variation between subjects. This implies that the hemiplegic subjects sat with more varied symmetry of weight distribution than the healthy subjects, but that, on average, the weight distribution was symmetrical.

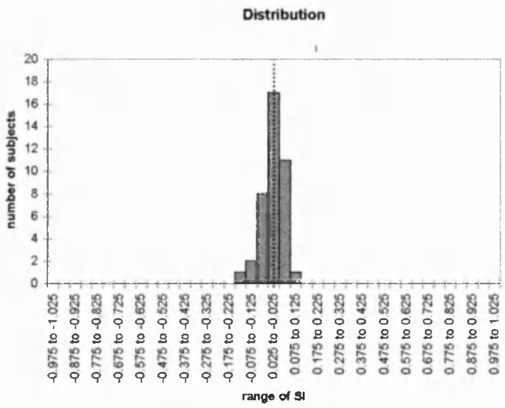


Figure 11.8 Distribution of mean symmetry index during sitting for healthy subjects (young and elderly combined).

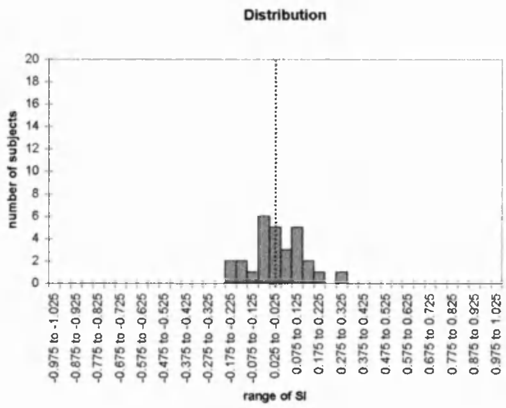


Figure 11.9 Distribution of mean symmetry index during sitting for hemiplegic subjects during week 0 (control and practice combined).

11.3.2 Control and practice groups

The relatively low number of subjects in the control and practice groups, the decrease in numbers over the test weeks due to patient discharge, and the relatively large variation between individual subjects, prevented the use of statistical tests to compare the control group and practice group results. Subsequently, comparison between the control group and practice group results was carried out with the use of descriptive statistics. The median, 5th, 25th, 75th and 90th percentiles for the control and practice group subjects for each of the test weeks are displayed in Table 11.5 and Table 11.6 respectively. The median, interquartile range and range are shown graphically in Figure 11.10.

	healthy	week 0	week 1	week 2	week 3	week 4	week 5	week 6
median	-0.010	-0.029	0.002	-0.020	0.046	0.033	0.046	0.061
25th percentile	-0.030	-0.074	-0.057	-0.092	-0.042	-0.017	0.019	0.011
75th percentile	0.031	0.014	0.043	0.049	0.073	0.097	0.083	0.128
interquartile range	*0.061*	*0.088*	*0.099*	*0.141*	*0.115*	*0.114*	*0.064*	*0.116*
5th percentile	-0.095	-0.188	-0.137	-0.142	-0.098	-0.059	-0.002	-0.024
95th percentile	0.057	0.147	0.169	0.157	0.189	0.167	0.182	0.219
90% range	*0.152*	*0.335*	*0.306*	*0.299*	*0.288*	*0.226*	*0.184*	*0.244*

Table 11.5 Median and percentiles for sitting SI. Control group subjects (SI).

	healthy	week 0	Week 1	week 2	week 3	week 4	week 5	week 6
median	-0.010	0.084	0.067	0.065	0.025	0.127	0.077	0.141
25th percentile	-0.030	0.058	-0.001	-0.027	-0.106	0.066	0.076	0.024
75th percentile	0.031	0.103	0.130	0.113	0.121	0.174	0.139	0.143
interquartile range	0.061	0.045	0.131	0.139	0.227	0.107	0.062	0.118
5th percentile	-0.095	-0.013	-0.101	-0.084	-0.169	-0.080	-0.052	-0.017
95th percentile	0.057	0.230	0.159	0.121	0.189	0.239	0.224	0.153
90% range	0.152	0.243	0.259	0.205	0.358	0.319	0.276	0.171

Table 11.6 Median and percentiles for sitting SI. Practice group subjects (SI).

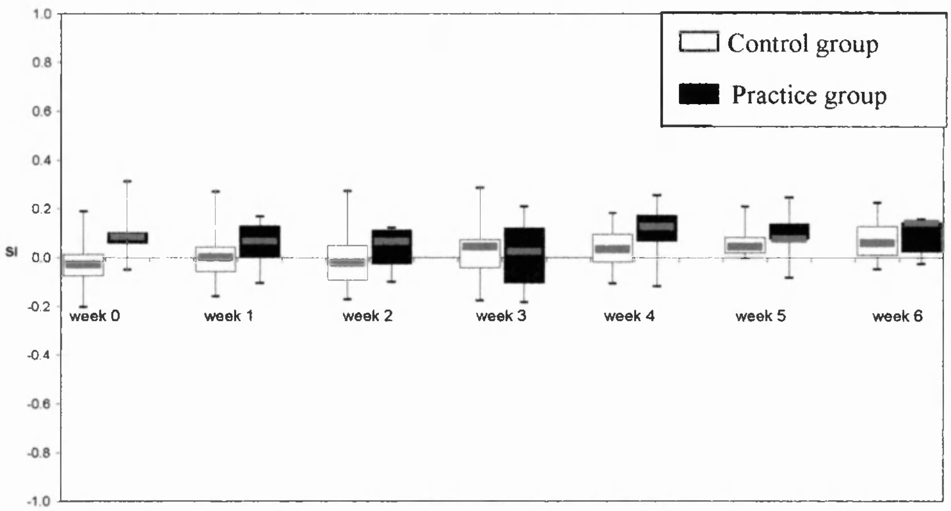


Figure 11.10 Medians and interquartile ranges of symmetry of sitting for control and practice group subjects over 7 test weeks

Control group versus healthy subjects

The median value for the symmetry of sitting for the control group subjects was very similar to that of the healthy subjects during test weeks 0, 1 and 2 (-0.01 for the healthy subjects and –0.03, 0.00 and –0.02 for the control group subjects during weeks 0, 1 and 2 respectively). During test weeks 3-6 the median values for the symmetry of sitting for the control group subjects were greater than that of the healthy subjects. The control group median values were greater than the 75^{th} percentile of the healthy subject data in weeks 3, 4 and 5 and greater than the 95^{th} percentile of the healthy subject data in week 6. The interquartile range and 90% range for the control group subjects were larger than that of the healthy subjects throughout the test weeks, although the 90% range decreased from week 0 through to week 5.

Practice group versus healthy subjects

The median values for the symmetry of sitting for the practice group subjects were greater than the healthy subject median value on all test weeks. The median values decreased, becoming closer to 0, from week 0 to 3 but were greater in weeks 4, 5 and 6. The practice group median values were greater than the 95^{th} percentile from the healthy subjects on all test weeks except week 3, when the practice group median was within the healthy subject interquartile range. As for the control group subjects, the interquartile and 90% range from the practice group subjects were greater than those for the healthy subjects.

Control group versus practice group

Comparing the control and practice group subject results indicates that the practice group subjects distributed considerably more weight on to the unaffected side than the control group during the initial (week 0) measurement. The differences between the symmetry of sitting by the control and practice group were less remarkable during test weeks 1-6, although the practice group subjects tended to distribute slightly more weight to the unaffected side than the control group throughout the entire test period. During all test weeks there was a large area of overlap in the interquartile range and range between the results of the control and practice group; this indicates that the small differences in the median values between the groups and test weeks may not have been consequential.

11.3.3 Effect of discharge on group results

The number of subjects in both the control and practice groups decreased over the test weeks as subjects were discharged from the trial. It is therefore possible that exploring the results for the groups of subjects may preclude the observation of any trends in the symmetry data of individual subjects. Examining the results of the subjects who had measurements taken on all 7 test weeks, and examining the results of subjects who were discharged home prior to week 6, may provide information pertaining to trends in the data over time. The median, interquartile range and range of the SI for subjects not discharged, discharged home and discharged for other reasons are plotted against the test week in Figure 11.11, Figure 11.12 and Figure 11.13. The patterns and trends in these graphs can be compared with the group results in Figure 11.10. The median values and the interquartile range data for the SI of each of these groups is displayed in Table 11.7 and Table 11.8.

Group	Discharge status	week 0	week 1	week 2	week 3	week 4	week 5	week 6
control	not discharged	-0.005	0.004	0.034	0.063	0.028	0.059	0.061
	discharged home	-0.045	0.027	-0.074	-0.002	0.033	0.014	
	discharged other	-0.154	-0.075	-0.109	-0.176			
practice	not discharged	0.069	0.126	0.110	0.096	0.127	0.077	0.141
	discharged home	0.095	-0.037	-0.059	-0.125			
	discharged other	0.177	0.102	0.058				

Table 11.7 Median values of symmetry of sitting for control and practice groups according to discharge status (SI).

Group	Discharge status	week 0	week 1	week 2	week 3	week 4	week 5	week 6
control	not discharged	0.143	0.081	0.127	0.088	0.124	0.079	0.116
	discharged home	0.094	0.093	0.079	0.099	0.074	0.024	
	discharged other	0.092	0.056	0.000	0.000			
practice	not discharged	0.027	0.114	0.049	0.177	0.107	0.062	0.118
	discharged home	0.012	0.068	0.041	0.000			
	discharged other	0.134	0.000	0.000				

Table 11.8 Interquartile range values for symmetry of sitting for control and practice groups according to discharge status (SI).

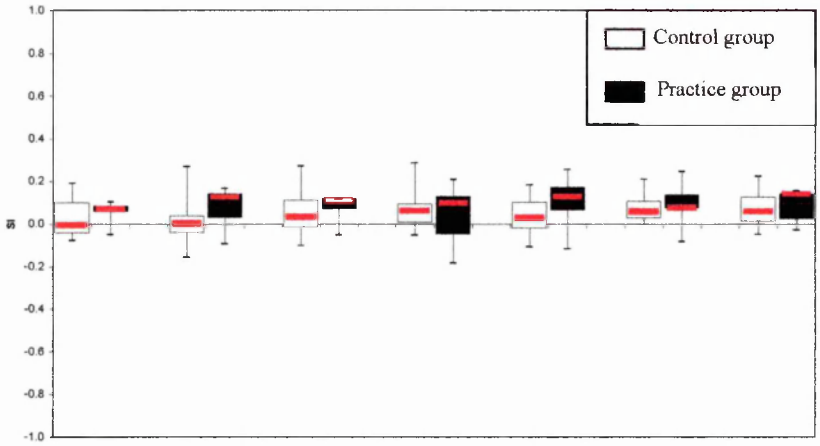


Figure 11.11 Median, interquartile range and range of symmetry of sitting for hemiplegic subjects completing 7 test weeks.

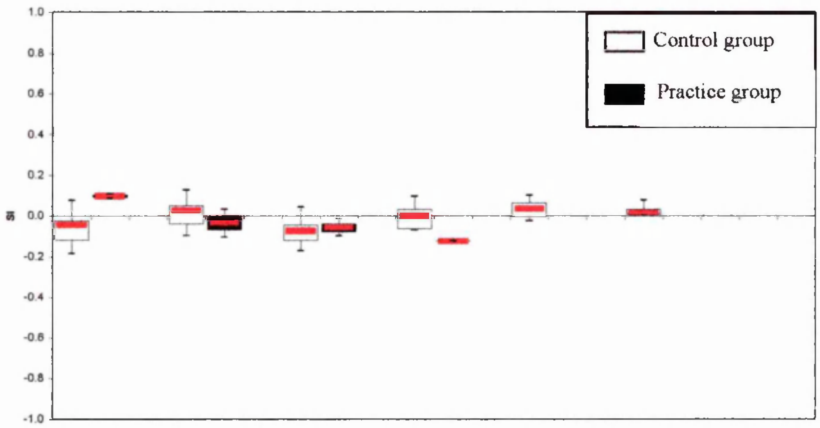


Figure 11.12 Median, interquartile range and range of symmetry of sitting for hemiplegic subjects discharged home before test week 6.

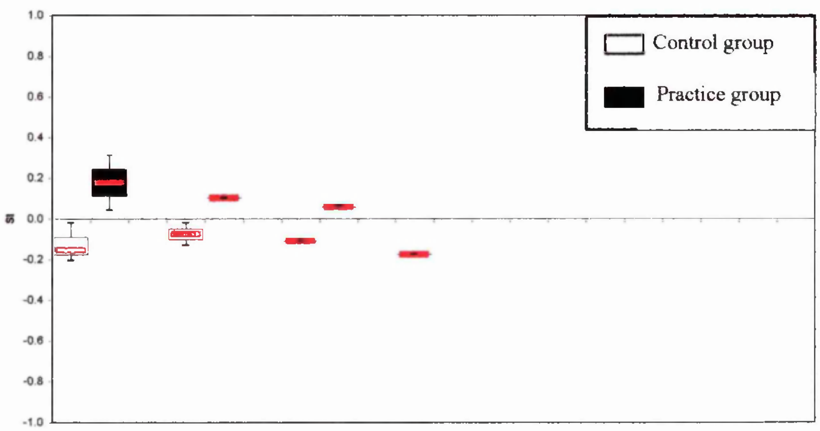


Figure 11.13 Median, interquartile range and range of symmetry of sitting for hemiplegic subjects discharged for reasons other than home before week 6.

Comparing the results from the whole control group with the results from the control group subjects who were tested for 7 weeks demonstrates that there was little difference between these two groups. This suggests that the influence of discharge on the control group results was minimal. Examining the data from the control group subjects who were discharged home supports this, as there was little difference in the results of these subjects and the subjects who were not discharged. The subjects who were discharged for other reasons exhibited greater weight bearing on the affected side; however, there were only 3 subjects in this group.

A difference can be observed between the results from the whole practice group and the results from the practice group subjects who were tested for 7 weeks. In the whole practice group results it was noted that the SI became closer to 0 (less weight on unaffected side) during test weeks 1, 2 and 3, but that there was increased weight bearing on the unaffected side during test weeks 4, 5, and 6. This pattern did not occur in the practice group subjects who were not discharged before week 6: there was little observable change in the SI from these subjects over the test weeks, with increased weight distribution to the unaffected side on all test weeks. An explanation for the difference between the whole practice group and the practice group subjects who were not discharged prior to week 6 is found in the observation of the results from the practice group subjects who were discharged home or discharged for other reasons. The SI for both of these groups decreased (increased weight on the affected side) over the test weeks. No practice group subjects were discharged during test weeks 4, 5 and 6; hence the influence of the different symmetry values from the discharged subjects occurred during test weeks 1, 2 and 3 but not during test weeks 4, 5 and 6.

Thus, while there was no apparent difference between the symmetry results for control group subjects who were or were not discharged during the study period, the case for the practice group subjects differed. Practice group subjects who were not discharged prior to the end of the study period exhibited symmetry results that did not change greatly over the test weeks. In contrast, practice group subjects who were discharged before the end of the study period demonstrated symmetry of weight bearing which shifted toward the affected side during the test weeks. However, the low number of subjects within the practice group limits the ability to generalise from these results.

11.3.4 Classification of ability

Although differences were observed between the healthy subjects and the stroke patients, these differences were small. Despite the small differences in the median values and the larger magnitude of the interquartile and 90% ranges in the patient groups, there was considerable overlap between the interquartile range and 90% range of the healthy subject data and that of the hemiplegic subjects. The overlap between the healthy subject data and the hemiplegic subject data indicates that the weight distribution of some of the individual hemiplegic subjects fell within the normative range, as defined by the healthy subjects. Whether a patient with stroke has an ability that is within or is not within the normative range is of ultimate importance in the assessment of that patient. The accurate classification of a patient's ability into "unable", "normal" or "abnormal" can be argued to provide essential information pertaining to the patient's ability.

The range of symmetry values determined for the healthy subjects encompasses the SI results for all 40 healthy subjects. This range potentially includes a proportion of statistical "outliers". A more appropriate definition of the "normal" range is therefore the range lying between the 5^{th} and 95^{th} percentiles of the healthy subject data (the 90% range). This definition was therefore used to determine whether individual patients exhibited symmetry of weight bearing in sitting which was within or was out with the "normal" range. The proportion of control and practice group subjects unable to achieve sitting, sitting with weight distribution out of the normal range ("abnormal") or sitting with weight distribution within the normal range ("normal") was determined using the definition of "normal" provided. These data are displayed in Table 11.9 and graphically in Figure 11.14 and Figure 11.15.

	Control			Practice			
	unable	abnormal	normal	unable	abnormal	normal	*Chi²*
Week 0	0%	42%	58%	0%	78%	22%	*0.077*
Week 1	0%	39%	61%	0%	63%	38%	*0.265*
Week 2	0%	47%	53%	0%	75%	25%	*0.189*
Week 3	0%	56%	44%	0%	83%	17%	*0.240*
Week 4	0%	53%	47%	0%	100%	0%	*0.058*
Week 5	0%	43%	57%	0%	80%	20%	*0.153*
Week 6	0%	60%	40%	0%	60%	40%	*1.000*

Table 11.9 Proportion of control and practice group subjects achieving normal weight distribution in sitting, and the Chi^2 statistic for the difference between the ability of the control and practice group subjects.

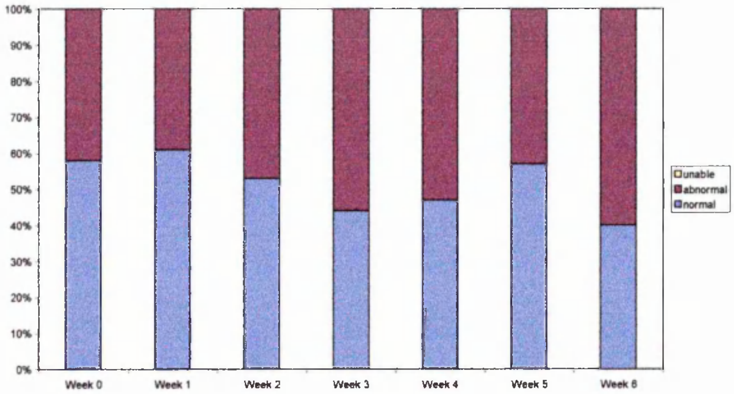


Figure 11.14 Proportion of control group subjects achieving normal weight distribution in sitting on different test weeks.

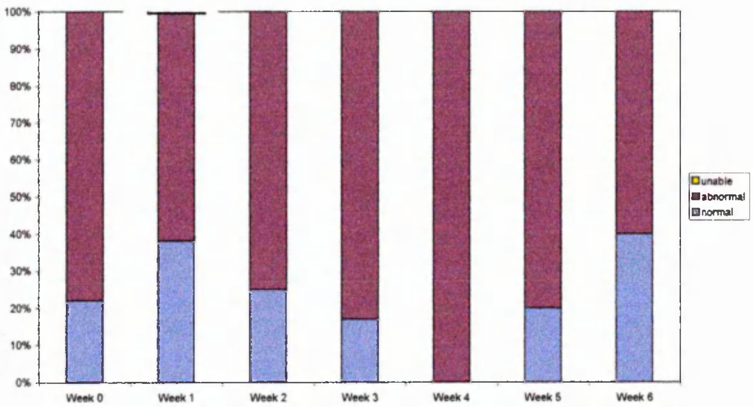


Figure 11.15 Proportion of practice group subjects achieving normal weight distribution in sitting on different test weeks.

The proportion of control to practice subjects achieving normal weight distribution in sitting was uneven at week 0, with a larger proportion of control group subjects achieving normal weight distribution; this trend remained throughout the test weeks. This trend results in distinctive differences between the control and practice group results, with a higher proportion of control group subjects achieving normal weight distribution throughout the test period. The statistical difference between the proportion of control and practice group subjects achieving normal and abnormal weight distribution can be determined using the Chi-squared test. This test determines the significance of the differences between two independent samples, determining whether the two samples differ with respect to the proportion of results in each classification. The Chi-squared values are displayed in Table 11.9. These demonstrate that there was no significant difference between the control and practice group results (Chi^2>0.05). Thus, although differences can be observed between the two groups these differences do not reach significance, at the chosen significance level (Chi^2<0.05).

There was no observable trend in the proportion of subjects achieving normal weight distribution for either the control or practice group over the test weeks. This observation was explored further by determining the change in each subject's ability between the first and last measurement of sitting. The number of control and practice group subjects with sitting ability that did and did not change relative to the normal is displayed in Table 11.10. The ability of a large proportion of both the control and practice group subjects did not change between the initial and final measurement: there was no change in the ability of 68% (0% + 26% + 42%) of the control group and in 89% (0% + 67% + 22%) of the practice group. A similar proportion of control and practice group subjects improved in their ability, with the initial weight distribution out with the normal range and the final weight distribution within (16% of the control group and 11% of the practice group). The ability of none of the practice group subjects deteriorated (starting normal and becoming abnormal) while the ability of 16% of the control group subjects became worse.

Ability at final measurement

Initial ability	Control			Practice		
	unable	**abnormal**	**normal**	**unable**	**abnormal**	**normal**
Unable	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
Abnormal	0 (0%)	5 (26%)	3 (16%)	0 (0%)	6 (67%)	1 (11%)
Normal	0 (0%)	3 (16%)	8 (42%)	0 (0%)	0 (0%)	2 (22%)

Table 11.10 Number (and percentage) of control and practice group subjects with ability to achieve normal symmetry of weight distribution in sitting changing between the initial and final measurement.

12. Results: standing

12.1 Raw data and analysis

The symmetry index was determined for each 10 second test of standing. Examples of the SI over the 10 seconds of data collection, as derived from the force data, for a young healthy, elderly healthy and hemiplegic subject are provided in Figure 12.1, Figure 12.2 and Figure 12.3.

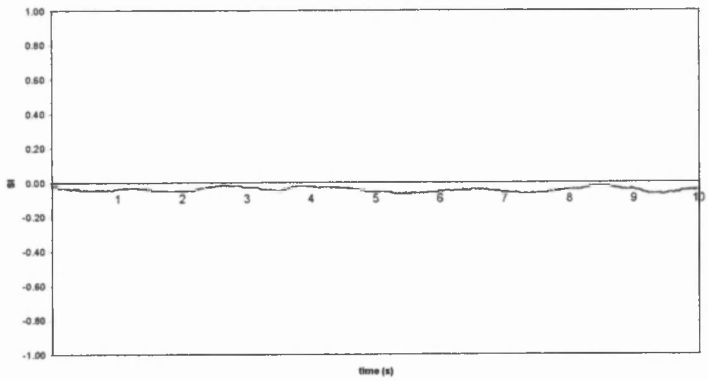


Figure 12.1 Symmetry of standing. Young healthy subject.

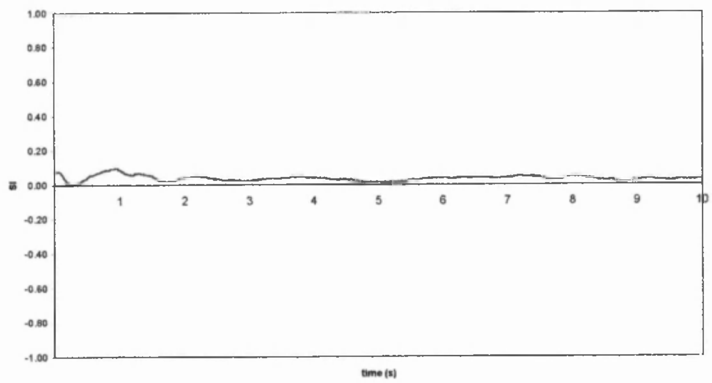


Figure 12.2 Symmetry of standing. Elderly healthy subject.

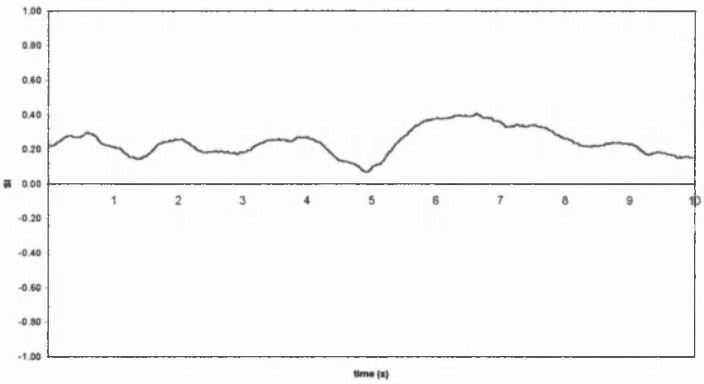


Figure 12.3 Symmetry of standing. Hemiplegic subject.

It can be observed that the SI varies over the 10 seconds of data collection. It has previously been identified that weight distribution in stance varies due to body sway (Black et al, 1982; Ring et al, 1988; De Weerdt et al, 1989; Ekdahl et al, 1989; Sackley, 1990, 1991; Sackley and Lincoln, 1991). It has also been identified that sway during stance, in both healthy and hemiplegic subjects is reciprocal (Mizrahi et al, 1989). This infers that, while variables such as the maximum, minimum and range of the SI would provide information relating to the magnitude of body sway, the mean SI was a valid variable in the assessment of weight distribution in stance. The use of the mean SI during stance as an outcome measure was advantageous as it allowed comparisons with values in the literature (e.g. Bohannon and Larkin, 1985; Caldwell et al, 1986; Dettmann et al, 1987; Sackley, 1990, 1991; Bohannon and Tinti-Wald, 1991; Sackley and Lincoln, 1991; Wu et al, 1996). Additionally the mean SI was relevant to the goals of clinical intervention, and allowed investigation of the relationship between the symmetry of weight distribution in sitting and standing. While the use of the mean SI did not provide a measure of postural sway in stance, the use of the mean SI met the aim of exploring symmetry of weight distribution. Hence, the mean SI over the 10 seconds of data collection for each measurement of standing was selected as the outcome variable and was determined for each test of standing.

12.2 Healthy subjects

The percentage close agreement for the 3 trials of standing for the young and elderly subjects are shown in Table 12.1. The variation between the 3 repeated measures was very low, with 90% of the differences between repeated measures being less than 0.07

for the young subjects and less than 0.10 for the elderly subjects. These values are comparable with the variation between the repeated measures of sitting (0.08 and 0.14 for young and elderly subjects respectively).

	PCA (80%)	PCA (90%)	PCA (95%)	PCA (100%)
Young	0.05	0.07	0.09	0.12
Elderly	0.09	0.10	0.11	0.19

Table 12.1 PCA and PEA for 3 repeated trials of mean symmetry of standing; young and elderly healthy subjects (SI).

Figure 12.4 illustrates the variation between the repeated trials for the elderly subjects; the variation between the repeated trials for the young subjects was similar in profile. The variation between the 3 repeated measures (90% of the differences between repeated measures were within 0.07 for the young subjects and 0.10 for the elderly subjects) was slightly less than the variation between the subjects (90% of the mean results from the group were within 0.19 for the young subjects and 0.21 for the elderly subjects). The mean of the 3 repeated measures for the symmetry of weight distribution during stance for each subject was used in the remaining analysis.

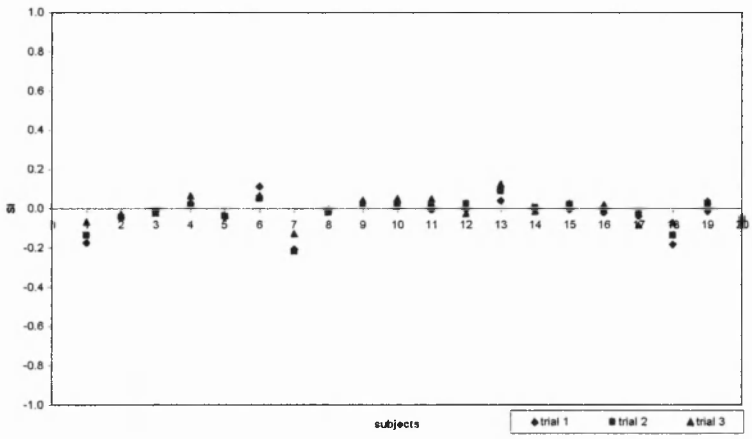


Figure 12.4 Mean symmetry index from 3 trials of standing. Elderly healthy subjects.

The distribution of the mean SI during standing is illustrated in Figure 12.5 and Figure 12.6, and the medians and percentiles of the SI during stance are displayed in Table 12.2. The results from the young subjects demonstrated a normal distribution, with the centre of the distribution located close to zero, indicating that the young healthy subjects tended to have symmetrical weight distribution in stance. However, the distribution of the data from the elderly subjects was slightly shifted to the right, indicating that the elderly subjects distributed more weight to the left side. This was confirmed by the median SI, which was 0.00 for the young subjects and 0.04 for the elderly subjects. Despite this difference the variation between the two groups of subjects was similar, with both groups demonstrating relatively low interquartile and 90% ranges (0.062 and 0.210 respectively for the young subjects; 0.126 and 0.194 respectively for the elderly subjects).

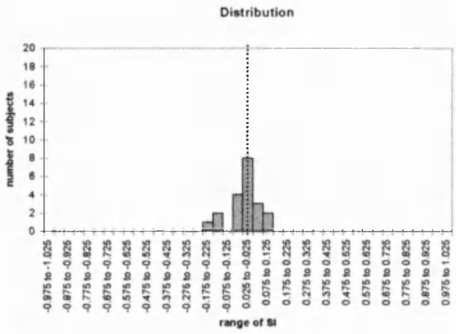


Figure 12.5 Distribution of mean symmetry index during standing for young healthy subjects.

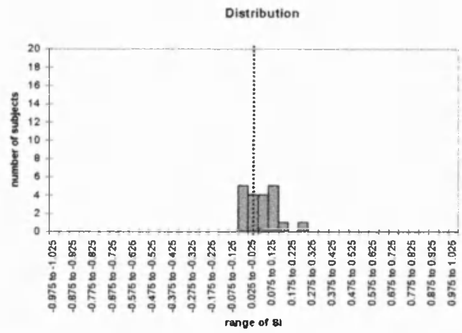


Figure 12.6 Distribution of mean symmetry index during standing for elderly healthy subjects.

	young	elderly
Median	-0.002	0.036
25th percentile	-0.042	-0.023
75th percentile	0.020	0.103
Interquartile range	0.062	0.126
5th percentile	-0.132	-0.055
95th percentile	0.078	0.139
90% range	0.210	0.194

Table 12.2 Medians and percentiles for standing. Young and elderly healthy subjects (SI).

Multiple regression was carried out to investigate the association between the SI during standing and the independent variables (gender, age, age group, height, body mass, lower-leg length, dominant hand). The R-square values and significance levels are listed in Table 12.3.

independent variable	age	age group	gender	mass	height	lower leg length	dominant hand
R^2	0.146	0.137	0.018	0.000	0.043	0.020	0.000
t_m	0.015	0.019	0.413	0.979	0.200	0.378	0.961
t_c	0.080	0.052	0.221	0.916	0.184	0.346	0.835
gradient							
constant							

Table 12.3 R-squared and significance values for association between mean standing SI and independent variables.

The definition of significant association previously identified (section 10.2) was used. There was a greater than 10% association between the mean SI during stance and the age (R^2 = 0.146) and age-group (R^2 = 0.137) of the subjects. This confirmed the previous observations pertaining to differences in the distribution of the mean results for the young and elderly subjects. The regression equations and significant t values for the association between the mean SI and the age and age-group (young or elderly) are shown in Table 12.3. The significant t values for the intercept of the regression line were slightly greater than the assigned level of significance ($t < 0.05$). However, these values were nearing significance and therefore suggested that there could potentially be significant associations between the mean SI during standing and the age of subjects. The association found with these results was not significant, according to the previous definitions, and it was therefore appropriate to combine the results from the young and elderly subjects in the subsequent analysis.

12.3 Hemiplegic subjects

12.3.1 Baseline measurement (week 0)

The low number of subjects achieving stance in week 0 (n=4) precluded the investigation of the distribution of the symmetry of stance prior to the start of the intervention. Similarly, the median and percentile values determined for the control group and practice group subjects during week 0 had to be interpreted with care, as data was available from only 2 control group and 2 practice group subjects.

12.3.2 Control and practice groups

As in the analysis of the symmetry of sitting for the control group and practice group subjects, the data were explored using descriptive statistics. The median, 5th, 25th, 75th and 90th percentiles for the control and practice group subjects for each of the test weeks are displayed in Table 12.4 and Table 12.5 respectively. The median, interquartile range and range are shown graphically in Figure 12.7.

	healthy	week 0	week 1	week 2	week 3	week 4	week 5	week 6
median	-0.001	0.087	0.010	0.110	0.091	0.033	0.058	0.048
25th percentile	-0.039	0.063	-0.113	0.073	-0.031	-0.038	-0.051	-0.057
75th percentile	0.060	0.110	0.151	0.152	0.144	0.135	0.187	0.116
interquartile range	0.100	0.047	0.264	0.079	0.175	0.173	0.238	0.173
5th percentile	-0.126	0.045	-0.177	-0.017	-0.078	-0.322	-0.217	-0.303
95th percentile	0.124	0.129	0.228	0.304	0.376	0.240	0.235	0.332
90% range	0.249	0.084	0.405	0.321	0.454	0.562	0.452	0.634

Table 12.4 Median and percentiles for standing SI. Control group subjects (SI).

	healthy	week 0	week 1	week 2	week 3	week 4	week 5	week 6
median	-0.001	0.102	0.191	0.090	0.266	0.190	0.018	0.099
25th percentile	-0.039	0.012	0.026	0.069	0.257	-0.138	-0.120	0.031
75th percentile	0.060	0.192	0.337	0.317	0.298	0.250	0.165	0.240
interquartile range	0.100	0.180	0.310	0.248	0.041	0.388	0.285	0.208
5th percentile	-0.126	-0.060	-0.066	-0.147	0.251	-0.155	-0.188	-0.226
95th percentile	0.124	0.264	0.384	0.449	0.325	0.268	0.252	0.277
90% range	0.249	0.324	0.449	0.596	0.074	0.423	0.440	0.503

Table 12.5 Median and percentiles for standing SI. Practice group subjects (SI).

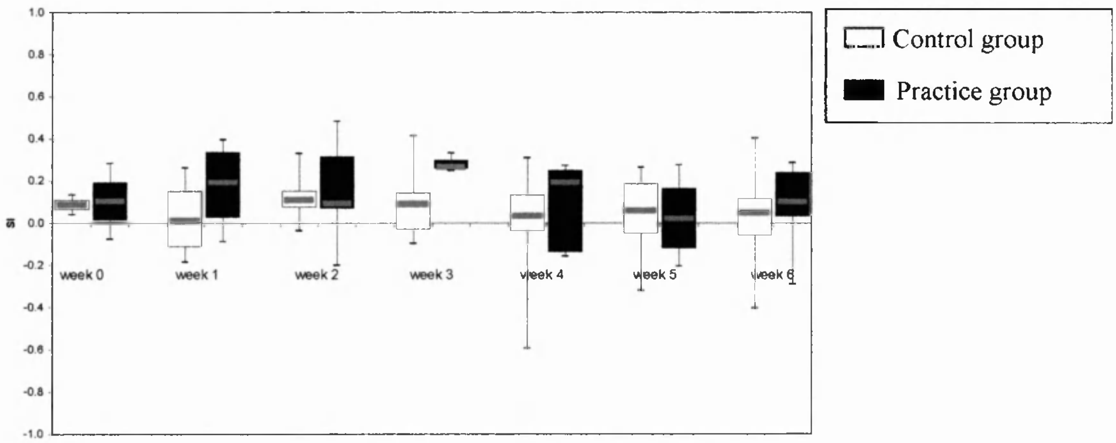


Figure 12.7 Medians and interquartile ranges of symmetry of stance for control and practice group subjects over 7 test weeks.

Control group versus healthy subjects

The median SI for the control group was greater than that of the healthy subjects on all test weeks. This suggests that the hemiplegic subjects had increased weight bearing to the unaffected side on all test weeks. The absolute values of the 25th percentile were less than the 75th percentile on all test weeks, further demonstrating the tendency for preferred weight bearing on the unaffected side. Although the interquartile range and 90% range of the control group subjects was less than that of the healthy subjects during week 0 (control group, n=2), during weeks 1-6 the range of data for the control group subjects was greater than the range for the healthy subjects.

Practice group versus healthy subjects

The comparison between the practice group and the healthy subjects was similar to the comparison between the control group and the healthy subjects. On all test weeks the median SI for the practice group subjects indicated that the practice group subjects tended to weight bear more through the unaffected than through the affected leg. This was confirmed by the practice group percentile values, with the absolute values of the 5th and 25th percentiles being less than the 95th and 75th percentiles respectively on all test weeks. With the exception of test week 3, the interquartile and 90% range for the practice group subjects was greater than that of the healthy subjects on all test weeks.

Control group versus practice group

The median and interquartile ranges of the SI for the control and practice group subject did not indicate any remarkable differences between the two groups. No trends could be observed in the data over the 7 weeks of data collection, with the exception of the continued tendency for increased weight distribution to the unaffected side by both groups.

12.3.3 Effect of discharge and inability to perform on group results

The high number of subjects who were unable to achieve stance during the initial test weeks, and the decrease in the numbers in both the control and practice groups due to discharge may have resulted in median and percentile results which were not representative of trends in individual subjects. The mean number of measurements taken from the control group subjects was 3.7, and from the practice group subjects was 3.1. The low number of measurements makes the exploration of trends in the data difficult. However, there are 2 methods that can be used to explore the possibility of trends in the data. The first of these involves investigating the trends in the data of subjects who completed more than a certain number of tests. This demonstrates the pattern of change over a number of test weeks: due to the nature of this process this is likely to primarily include the subjects who had the ability to stand but who were not discharged from the trial. The second method of exploring trends in the data is to determine the variables from the first and last test recorded from all of the subjects achieving stance during the test period. This method includes a higher number of subjects than the first method, and will generally include subjects regardless of discharge status. Although the number of weeks between the first and last test varied between subjects, this method has the potential to indicate generalised group trends.

In order to use the first method of analysis it was necessary to determine the minimum number of test weeks that subjects were to have completed to allow inclusion in the analysis. Exploration of the number of subjects completing tests over the test period revealed that only 1 of the practice group subjects had completed more than 4 consecutive weekly tests of stance. Therefore the use of only subjects completing more than 4 consecutive tests would not include sufficient subjects for analysis. Therefore analysis was carried out using the data from any subject who completed 4 or more tests of stance. This included 68% (n=13) of the control group subjects, and 44% (n=4) of the practice group subjects. Figure 12.8 displays the median, interquartile range and range of the symmetry of weight distribution in standing for the control and practice group subjects completing 4 or more tests of stance. The pattern of results for the control and practice group subjects who completed 4 or more tests of stance was not observably different to the results obtained from the whole group (Figure 12.7). This suggests that the results from the subjects only managing to complete relatively few (3 or less) tests of stance did not unduly influence the patterns and trends observed in the data.

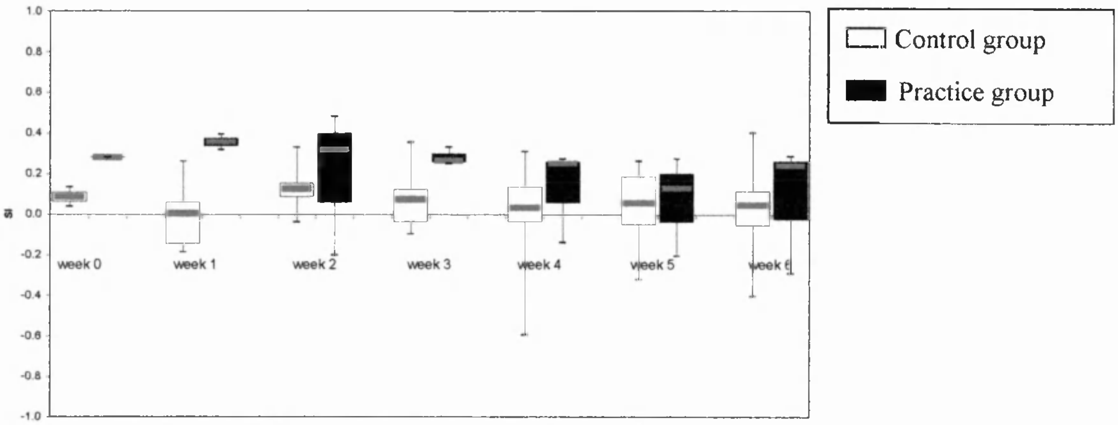


Figure 12.8 Median, interquartile range and range of symmetry of standing for hemiplegic subjects completing 4 or more tests of stance.

The second method of investigating trends in the standing data included a greater number of subjects than the previous method, and can therefore be argued to be a more robust analysis. This method involved determining the mean standing symmetry for both the first and last test for each subject who attained stance during the 7 weeks of testing. Table 12.6 displays the median and interquartile range of the SI during standing from the first and last test for the control and practice group subjects. These figures demonstrate that both the control and practice group subjects distributed more weight to the unaffected side during the last test than during the first test. Although it can be noted for both the control and practice group subjects that, while the degree of asymmetry increased between the first and last test and the variation between subjects decreased (as reflected in the decrease in the interquartile range), the magnitude of these changes were small. It was therefore difficult to determine any trends in the pattern of symmetry of stance data: this concurs with the conclusions drawn from the whole-group data.

		control	practice
median	**1st test**	0.015	0.056
	last test	0.075	0.094
interquartile range	**1st test**	0.201	0.364
	last test	0.189	0.187

Table 12.6 Median and interquartile range for symmetry of stance during subjects' first and last tests (SI).

12.3.4 Classification of ability

Using the definition of 'normal' values determined in the analysis of the sitting data (being equal to the 90% range from the healthy subjects) the proportion of hemiplegic subjects with symmetry of weight distribution in stance within the normal range was determined. Additionally, the proportion of subjects unable to perform the task was assessed. The proportion of subjects with "normal" weight distribution in stance is illustrated in Table 12.7, and in Figure 12.9 and Figure 12.10.

	Control			Practice			
	unable	**abnormal**	**normal**	**unable**	**abnormal**	**normal**	***Chi^2***
Week 0	90%	5%	5%	78%	11%	11%	*0.711*
Week 1	45%	33%	22%	50%	25%	25%	*0.914*
Week 2	30%	35%	35%	37%	38%	25%	*0.861*
Week 3	18%	29%	53%	50%	50%	0%	*0.064*
Week 4	18%	44%	38%	0%	100%	0%	*0.085*
Week 5	20%	47%	33%	0%	75%	25%	*0.509*
Week 6	28%	27%	45%	0%	60%	40%	*0.306*

Table 12.7 Proportion of control and practice group subjects achieving normal weight distribution in standing, and the Chi^2 statistic for the difference between the ability of the control and practice group subjects.

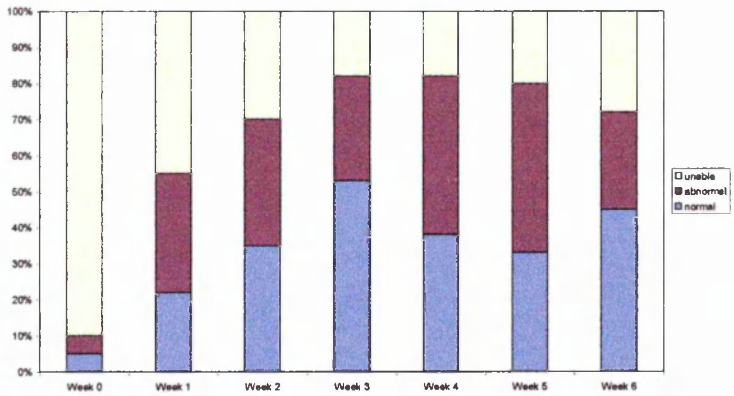


Figure 12.9 Proportion of control group subjects achieving normal weight distribution in standing on different test weeks.

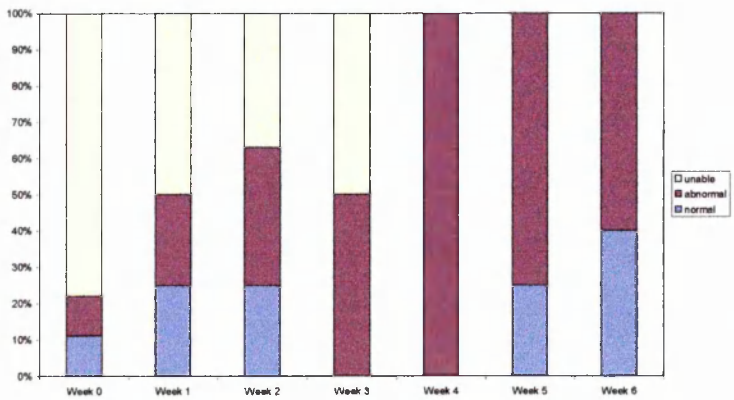


Figure 12.10 Proportion of practice group subjects achieving normal weight distribution in standing on different test days.

The proportion of subjects unable to stand during the initial test week (week 0) was very high for both the practice (78%) and control (90%) groups. In both groups the proportion of subjects unable to stand reduced over the test weeks. However, by week 4 the entire practice group was able to stand, while around 20% of the control group subjects remained unable. The proportion of control group subjects achieving normal weight distribution increased from week 0 to week 3, and remained above 30% for the remaining test weeks. A smaller proportion of practice group subjects than control group subjects achieved normal weight distribution in stance during test weeks 2 – 6. Subsequently, during the latter test weeks the practice group had a greater proportion of subjects who, although able to stand, had symmetry indices out with the normal range. While these differences can be observed in the ability of the control and practice group subjects, statistical comparison using the Chi-squared test revealed that there were no significant differences between the ability of the two groups. The Chi-squared values are displayed in Table 12.7.

The number of control and practice group subjects with standing ability that did and did not change between their first and last test day is shown in Table 12.8. These results demonstrate that, while a high proportion of control (26%+38%+26% = 90%) and practice (11%+33%+33% = 77%) group subjects were unable to perform standing during the first test week, 64% (38%+26%) of the control group subjects and 66% (33%+33%) of the practice group subjects attained the ability to stand during the test period. Comparing the ability of the control and practice group subjects demonstrates that there was little difference in the proportion of subjects from the two groups attaining "abnormal" or "normal" symmetry of stance over the test period.

Ability at final measurement

Initial ability	Control			Practice		
	Unable	abnormal	normal	unable	abnormal	normal
Unable	5 (26%)	7 (38%)	5 (26%)	1 (11%)	3 (33%)	3 (33%)
Abnormal	0%	0%	1 (5%)	0%	1 (11%)	0%
Normal	0%	0%	1 (5%)	0%	0%	1 (11%)

Table 12.8 Number (and percentage) of control and practice group subjects with ability to achieve normal symmetry of weight distribution in standing changing between the initial and final measurement.

13. Results: Rising to stand

13.1 Raw data and analysis

The symmetry index, SI, was determined for each measured rise to stand. Examples of the SI during rising to stand for a young, elderly, and hemiplegic subject are provided in Figure 13.1, Figure 13.2 and Figure 13.3. In addition to displaying the SI, these graphs display the point where seat-off occurred and the points where the movement was identified to start and stop.

13.1.1 Calculation of phases

Rising to stand was divided into a seat-on (phase 1) and a seat-off (phase 2) phase. In order to ensure that the division of the data into two phases, and the identification of the start and end of the movement, were repeatable these were computed from the raw data. Movement was defined as occurring if the total vertical force varied more than plus or minus 2 standard deviations from the mean vertical force determined during rest.

Seat-on phase

The start of movement was determined by calculating the mean and standard deviation of the total vertical force over 1 second of data collection immediately prior to the command for the subject to start moving. When the vertical force became greater than the mean resting vertical force by + 2 standard deviations, or became less than the mean resting vertical force by – 2 standard deviations, it was assumed that movement was occurring. To ensure that this was not an anomalous change, due to postural sway, the movement was not assumed to have started until the vertical force had remained out of the 'normal' range for at least 8 out of 10 consecutive samples.

The end of this phase was defined as the moment in time when seat-off occurred. This point occurred when the vertical force recorded by the seat section became zero. (To allow for the slight noise within the measurement system and the potential effects of foam on the seat of the chair, this point was, in fact, determined as occurring when the force through the seat became less than 1N.)

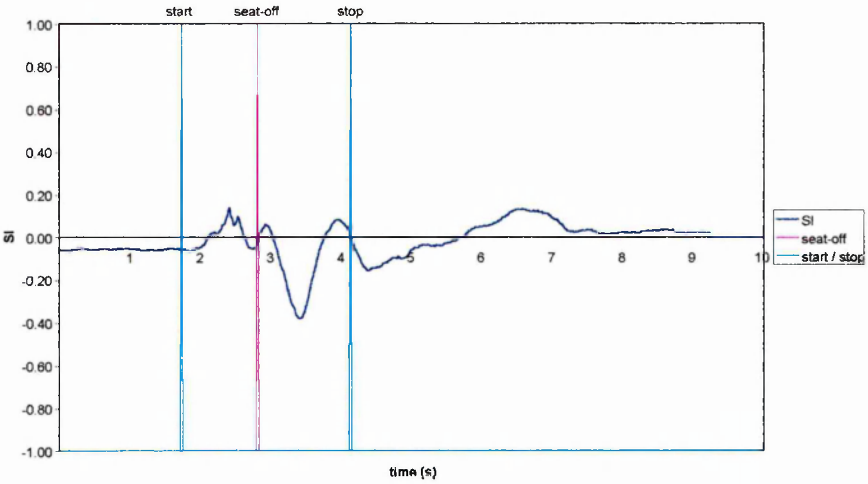


Figure 13.1 Symmetry of rising to stand. Young healthy subject.

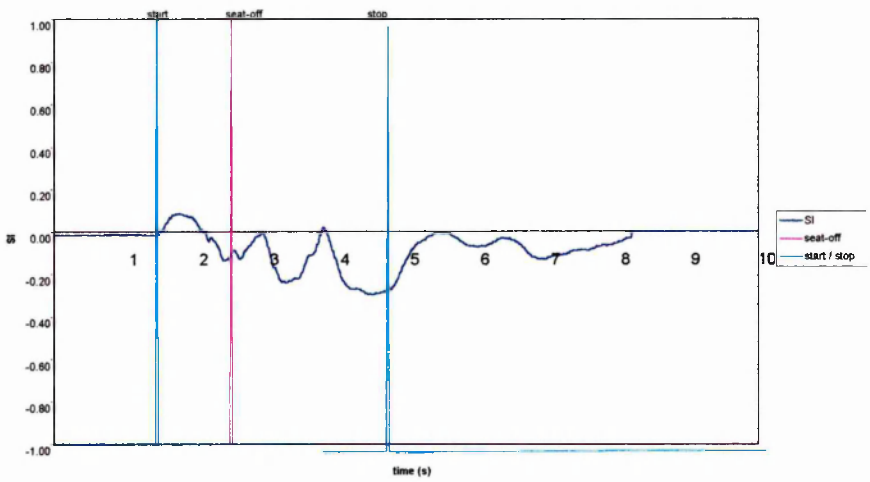


Figure 13.2 Symmetry of rising to stand. Elderly healthy subject.

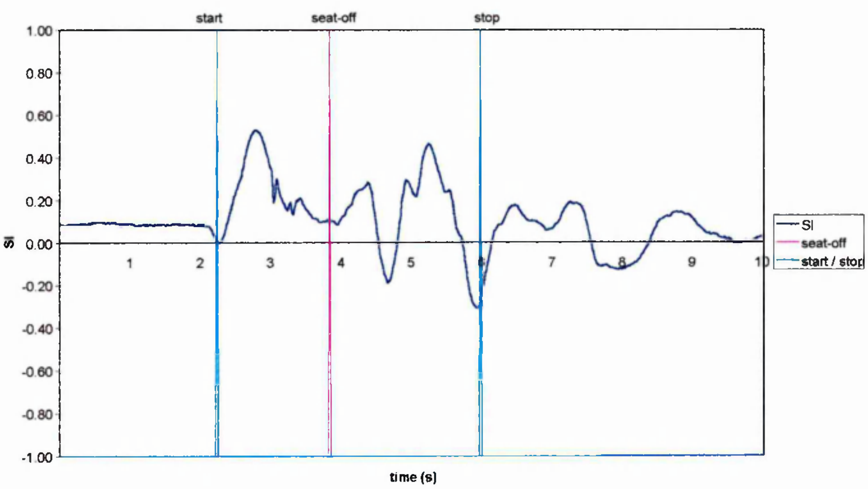


Figure 13.3 Symmetry of rising to stand. Hemiplegic subject.

Seat-off phase

This phase started at seat-off.

The end of movement was determined by calculating the mean and standard deviation of the total vertical force over 1 second of data collection, at a point 2 seconds after the subject was observed to stop moving. When the vertical force was within the range defined by the mean ± 2 standard deviations from the mean, it was assumed that movement had ceased. To ensure that this was not an anomalous finding, as the vertical force moved through the range, the movement was not assumed to have stopped until the vertical force remained within the 'normal' range for at least 8 out of 10 consecutive samples.

Figure 13.1, Figure 13.2 and Figure 13.3 illustrate that there was considerable variation in the SI during rising to stand in both healthy and hemiplegic subjects. In a study that measured the symmetry of weight distribution under the feet during the seat-off phase of rising to stand in healthy and hemiplegic subjects, Durward (1994) reported the mean, maximum, minimum and range of the SI. However, analysis of this data revealed that, while the mean values were highly reproducible, there was greater variation in the maximum, minimum and range of the SI. Although Durward reported and discussed the maximum, minimum and range of the SI, it was the mean SI which was found to be the most informative regarding hemiplegic patients' ability and which was found to be consistent with values in the literature. While omitting to determine and report variables pertaining to the variation in the SI during rising to stand may potentially remove valuable information relating to consistency of performance, there were several advantages to the use of the mean SI as the outcome variable. These included the higher degree of reproducibility found in previous studies (Durward, 1994) and the relationship of this variable to the goals of clinical rehabilitation of rising to stand for subjects with hemiplegia. The mean weight distribution is a variable that has been widely reported in the literature, both for this function and for other functions. The mean SI is a variable that provides clinically relevant information and that may be compared and related to variables reported in the literature and to the outcome variables determined for other functions in this study.

Hence the mean SI during the seat-on and seat-off were selected as the outcome variables and were determined for each test of rising to stand.

In addition to the use of the mean SI, the time taken to rise to stand was determined. This variable was included as a measure of ability as Durward (1994) proposed that that the time to rise to stand provided a basic but fundamental indicator of functional ability in stroke patients.

13.2 Healthy subjects

The percentage close agreement for each of the two phases of the 3 trials of rising to stand for the young and elderly subjects are provided in Table 13.1. The variation between the 3 repeated measures of the mean SI during the seat-on phase was low (90% of differences less than 0.07 for young and 0.12 for elderly subjects), and was similar to the variation found in repeated trials of quiet sitting (90% of differences less than 0.08 for young and 0.14 for elderly subjects). The variation between the 3 repeated measures of the mean SI during the seat-off phases was greater than that of the seat-on phase, and also greater than that found in repeated trials of quiet stance. 90% of the differences in repeated measures for the seat-off phase were less than 0.19 for the young subjects and 0.25 for the elderly subjects, while for repeated trials of quiet stance these values were 0.07 and 0.10 respectively. The variation in repeated measures of the time taken to stand up was relatively low with 90% of the differences being less that 1 second, for the young and elderly subjects.

		PCA (80%)	PCA (90%)	PCA (95%)	PCA (100%)
SEAT-ON PHASE (SI)	*Young*	0.05	0.07	0.08	0.12
	Elderly	0.09	0.12	0.14	0.17
SEAT-OFF PHASE (SI)	*Young*	0.16	0.19	0.28	0.42
	Elderly	0.16	0.25	0.39	0.45
TIME (S)	*Young*	0.8	1.0	1.4	1.9
	Elderly	0.7	0.9	1.0	2.7

Table 13.1 PCA for reported variable from 3 repeated trials of rising to stand; young and elderly healthy subjects.

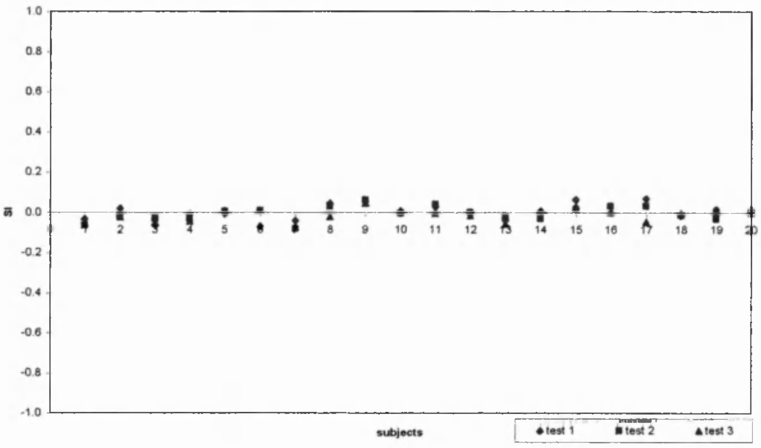


Figure 13.4 Mean symmetry index from 3 trials of rising to stand : seat-on phase. Young healthy subjects.

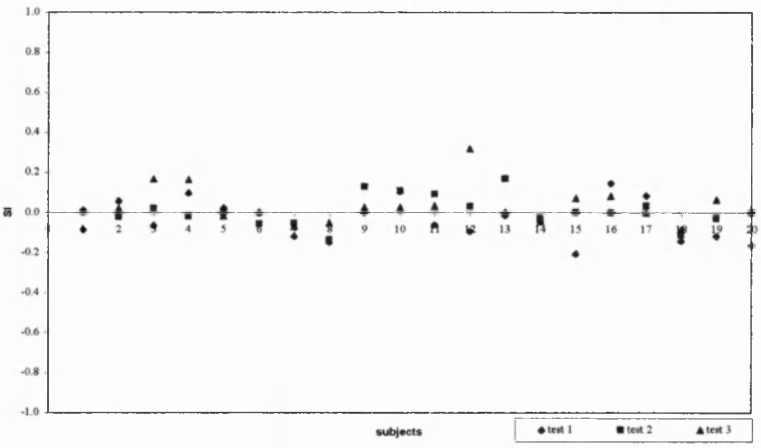


Figure 13.5 Mean symmetry index from 3 trials of rising to stand: seat-off phase. Young healthy subjects.

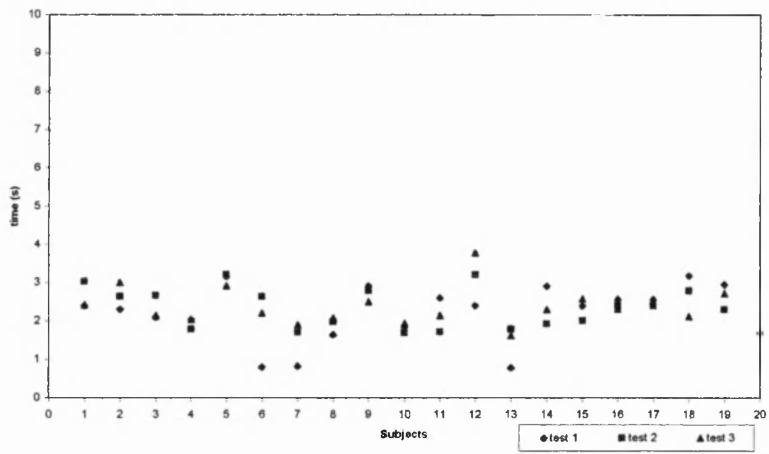


Figure 13.6 Mean time taken to stand up from 3 trials of rising to stand. Young healthy subjects.

Figure 13.4, Figure 13.5 and Figure 13.6 illustrate the variation between the SI for the seat-on and seat-off phases and between the time taken during repeated tests of rising to stand for the young healthy subjects; the variation between the repeated trials for the elderly subjects was similar in profile. The greater magnitude of variation in repeated measures of the seat-off phase, which accounts for the increased PCA values, can be observed in Figure 13.5. 90% of the differences between repeated measures of the SI during the seat-on phase were less than 0.07 for the young subjects, and the mean of the repeated measures of the SI during the seat-on phase for 90% of the young subjects were in a range of 0.09. For the elderly subjects these values were 0.12 and 0.14 respectively. For the seat-off phase these values were 0.19 and 0.19 respectively for the young subjects; and 0.25 and 0.27 respectively for the elderly subjects. For the time taken these equivalent values were 1.0 and 1.6 for the young subjects and 0.9 and 1.0 for the elderly subjects. Thus, despite the differences in the variation between the repeated trials for the different outcome variables, the variation between subjects remained relatively similar to the variation between trials, for the SI during the seat-on and seat-off phases and for the time taken. The mean of the 3 repeated measures for the symmetry of weight distribution during the two rising to stand phases and the time taken to stand up were therefore appropriate outcome measures for each individual subject. The mean of each variable relating to rising to stand was reported in all further analysis.

The distribution of the mean variables during rising to stand for the young and elderly healthy subjects are displayed in Figure 13.7 - Figure 13.12. These histograms demonstrate that the distribution of the mean variables did not exhibit skew and that the symmetry variables were approximately centred on 0. The median values and 5th, 25th, 75th and 95th percentiles for each of the variables for the young and elderly healthy subjects are displayed in Table 13.2. The median values for the mean symmetry during the seat-on and seat-off phase were close to 0, confirming the observations made from the histograms. The interquartile and 90% range of the SI for both the young and elderly subjects was greater during the seat-off phase than during the seat-on phase. The interquartile and 90% range for the seat-on phase was similar to that during quiet sitting, while the interquartile and 90% range for the seat-off phase was greater than that during quiet sitting for both the young and elderly healthy subjects. Thus the variation between subjects was greater during the seat-off phase of rising to stand than the variation during quiet sitting, or the seat-on phase of rising to stand.

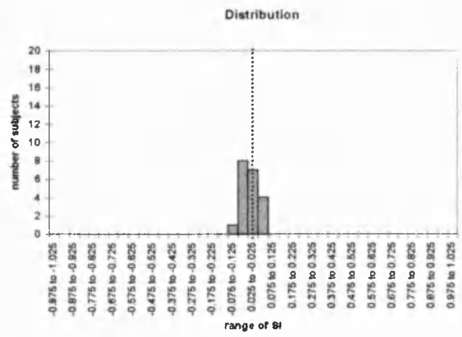


Figure 13.7 Distribution of mean symmetry index during seat-on phase of rising to stand in young healthy subjects.

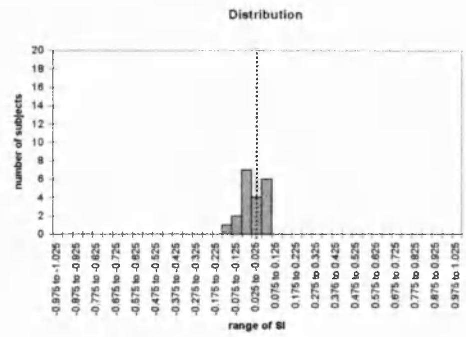


Figure 13.8 Distribution of mean symmetry index for seat-on phase of rising to stand in elderly healthy subjects.

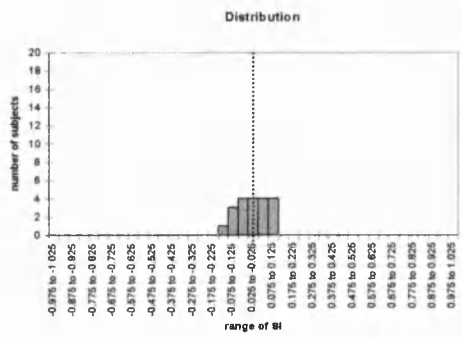


Figure 13.9 Distribution of mean symmetry index during seat-off phase of rising to stand in young healthy subjects.

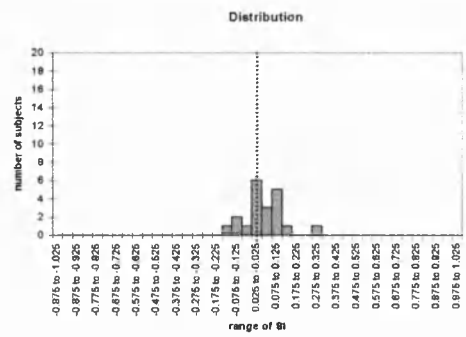


Figure 13.10 Distribution of mean symmetry index during seat-off phase of rising to stand in elderly healthy subjects.

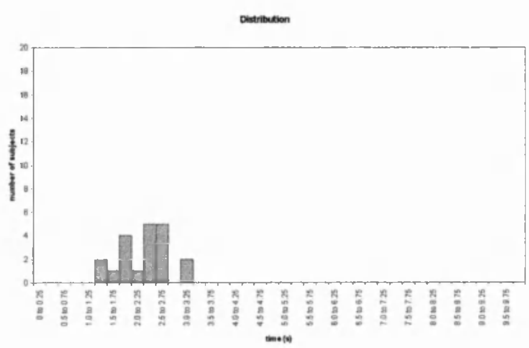


Figure 13.11 Distribution of mean time taken to rise to stand in young healthy subjects.

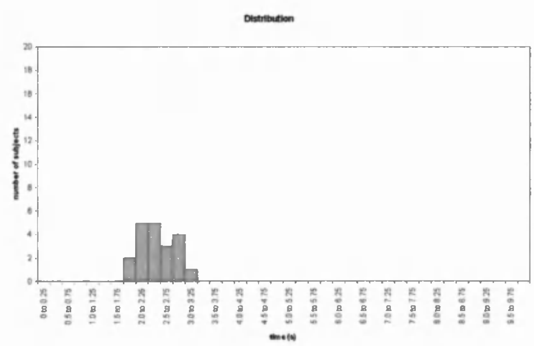


Figure 13.12 Distribution of mean time taken to rise to stand in elderly healthy subjects.

The median values for the mean time taken to rise to stand were similar for both the young and elderly healthy subjects, being approximately 2.3s. The interquartile and 90% range for the time taken was slightly greater for the young healthy subjects than for the elderly healthy subjects. The values for the 75th and 95th percentiles (upper time limit) were similar for both the young and elderly healthy subjects. The values for the 5th and 25th percentiles (lower time limit) were lower for the young subjects than for the elderly subjects. This suggests that the differences in the ranges of time were due to some of the young subjects managing to complete the movement in less time than the elderly subjects.

	Mean SI seat-on phase (SI)		**Mean SI seat-off phase (SI)**		**Mean time to rise to stand (s)**	
	young	**elderly**	**young**	**elderly**	**young**	**elderly**
median	-0.024	-0.025	0.011	0.026	2.353	2.307
25th percentile	-0.033	-0.049	-0.040	-0.017	1.895	2.147
75th percentile	0.012	0.028	0.055	0.090	2.650	2.652
interquartile range	0.045	0.077	0.095	0.108	0.755	0.505
5th percentile	-0.051	-0.086	-0.116	-0.120	1.469	1.955
95th percentile	0.062	0.061	0.081	0.135	3.095	3.003
90% range	0.112	0.146	0.197	0.255	1.626	1.048

Table 13.2 Medians and percentiles for symmetry and time data during rising to stand. Young and elderly healthy subjects.

Multiple regression was carried out to investigate the association between the symmetry and time variables and the independent variables (gender, age, age-group, height, body mass, lower-leg length, dominant hand). The R-squared and significance values are listed in Table 13.3 - Table 13.5. The definition of significant association previously identified (section 10.2) was used. There was greater than 10% association between the mean SI during the seat-on phase and the gender of the subjects (R^2 = 0.224). However, the significance of the constant variable in the regression equation was low (significant t = 0.334). The association between variables was less than 10% for all other independent and dependent variables. There were therefore no significant associations between the mean SI for the seat-on or seat-off phase or the time taken to rise and the independent variables (gender, age, height, body mass, lower-leg length, dominant hand).

independent variable	age	age group	gender	mass	height	lower leg length	dominant hand
R^2	0.005	0.009	0.224	0.019	0.090	0.081	0.061
t_m	0.661	0.552	0.002	0.401	0.060	0.078	0.124
t_c	0.580	0.929	0.334	0.263	0.047	0.056	0.360
gradient							
constant							

Table 13.3 R-squared and significance values for association between mean SI during seat-on phase of rising to stand and independent variables.

independent variable	age	age group	gender	mass	height	lower leg length	dominant hand
R^2	0.038	0.035	0.012	0.018	0.004	0.007	0.009
t_m	0.230	0.249	0.500	0.405	0.706	0.601	0.562
t_c	0.533	0.430	0.254	0.492	0.744	0.649	0.411
Gradient							
Constant							

Table 13.4 R-squared and significance values for association between mean SI during seat-off phase of rising to stand and independent variables.

Independent variable	age	age group	gender	mass	height	lower leg length	dominant hand
R^2	0.038	0.029	0.006	0.000	0.002	0.005	0.004
t_m	0.227	0.213	0.639	0.922	0.767	0.664	0.715
t_c	0.000	0.189	0.000	0.000	0.154	0.063	0.000
gradient							
constant							

Table 13.5 R-squared and significance values for association between mean time taken to rise to stand and independent variables.

13.3 Hemiplegic subjects

13.3.1 Baseline measurement (week 0)

The low number of subjects achieving rising to stand in week 0 (n=2) precluded the investigation of the distribution of the symmetry and time variables during rising to stand prior to the start of the intervention. In Table 13.6 - Table 13.11 the median and percentile values determined for the control group and practice group subjects during week 0 are listed. However these values are derived from only one subject for both the control group and practice group, and subsequently cannot be generalised.

13.3.2 Control and practice groups

The relatively low number of subjects in the control and practice groups, the low number of subjects able to achieve rising to stand, the decrease in numbers over the test weeks due to patient discharge, and the relatively large variation between individual subjects, prevented the use of statistical tests to compare the control group and practice group results. Subsequently, comparison between the control group and practice group results was carried out with the use of descriptive statistics. The median, percentiles and interquartile and 90% ranges of the symmetry and time data are shown in Table 13.6 - Table 13.11. The median and interquartile ranges of the symmetry data are shown graphically in Figure 13.13, Figure 13.14 and Figure 13.15.

	healthy	week 0	week 1	week 2	week 3	week 4	week 5	week 6
median	-0.02	-0.11	0.01	0.08	0.11	0.12	0.10	0.10
25th percentile	-0.04	-0.11	-0.02	0.06	0.06	0.09	0.04	0.00
75th percentile	0.01	-0.11	0.11	0.15	0.21	0.24	0.14	0.21
interquartile range	*0.05*	*0.00*	*0.13*	*0.09*	*0.15*	*0.15*	*0.11*	*0.22*
5th percentile	-0.08	-0.11	-0.05	0.01	-0.11	0.07	0.01	-0.07
95th percentile	0.06	-0.11	0.34	0.51	0.29	0.29	0.16	0.30
90% range	*0.14*	*0.00*	*0.39*	*0.50*	*0.40*	*0.23*	*0.15*	*0.37*

Table 13.6 Median and percentiles for SI during seat-on phase of rising to stand. Control group subjects (SI).

	healthy	week 0	week 1	week 2	week 3	week 4	week 5	week 6
median	-0.02	0.00	0.04	0.05	0.01	0.01	0.00	0.06
25th percentile	-0.04	0.00	-0.01	0.00	-0.08	-0.07	-0.07	0.01
75th percentile	0.01	0.00	0.10	0.10	0.08	0.03	0.08	0.07
interquartile range	*0.05*	*0.00*	*0.11*	*0.10*	*0.16*	*0.09*	*0.14*	*0.06*
5th percentile	-0.08	0.00	-0.05	-0.10	-0.15	-0.13	-0.12	-0.09
95th percentile	0.06	0.00	0.14	0.12	0.11	0.04	0.13	0.10
90% range	*0.14*	*0.00*	*0.19*	*0.22*	*0.26*	*0.17*	*0.25*	*0.19*

Table 13.7 Median and percentiles for SI during seat-on phase of rising to stand. Practice group subjects (SI).

	healthy	week 0	week 1	week 2	week 3	week 4	week 5	week 6
median	0.02	-0.08	0.09	-0.01	0.14	0.10	0.17	0.10
25th percentile	-0.03	-0.08	-0.05	-0.06	0.09	0.06	0.06	0.05
75th percentile	0.08	-0.08	0.34	0.10	0.23	0.18	0.19	0.24
interquartile range	*0.11*	*0.00*	*0.38*	*0.16*	*0.14*	*0.12*	*0.14*	*0.19*
5th percentile	-0.12	-0.08	-0.18	-0.09	-0.09	-0.10	-0.02	-0.05
95th percentile	0.12	-0.08	0.72	0.27	0.42	0.21	0.25	0.56
90% range	*0.24*	*0.00*	*0.89*	*0.36*	*0.52*	*0.31*	*0.27*	*0.61*

Table 13.8 Median and percentiles for SI during seat-off phase of rising to stand. Control group subjects (SI).

	healthy	week 0	week 1	week 2	week 3	week 4	week 5	week 6
median	0.02	0.29	0.13	0.14	0.27	0.19	0.26	0.16
25th percentile	-0.03	0.29	0.13	0.05	0.16	0.09	0.08	0.05
75th percentile	0.08	0.29	0.21	0.20	0.32	0.32	0.53	0.29
interquartile range	*0.11*	*0.00*	*0.08*	*0.15*	*0.15*	*0.22*	*0.46*	*0.24*
5th percentile	-0.12	0.29	0.13	-0.13	-0.09	0.02	-0.07	-0.18
95th percentile	0.12	0.29	0.26	0.60	0.41	0.42	0.75	0.59
90% range	*0.24*	*0.00*	*0.14*	*0.73*	*0.50*	*0.40*	*0.82*	*0.77*

Table 13.9 Median and percentiles for SI during seat-off phase of rising to stand. Practice group subjects (SI).

	healthy	week 0	week 1	week 2	week 3	week 4	week 5	week 6
median	2.31	10.64	4.42	5.31	4.83	3.98	4.66	4.57
25th percentile	2.10	10.64	3.46	3.37	3.75	3.02	3.68	4.50
75th percentile	2.63	10.64	5.54	8.80	6.59	4.81	4.80	4.64
interquartile range	*0.53*	*0.00*	*2.08*	*5.43*	*2.84*	*1.80*	*1.12*	*0.14*
5th percentile	1.68	10.64	3.44	2.66	2.18	2.13	2.11	4.45
95th percentile	3.06	10.64	5.91	10.33	7.44	9.87	5.33	4.69
90% range	*1.39*	*0.00*	*2.46*	*7.67*	*5.26*	*7.74*	*3.22*	*0.24*

Table 13.10 Median and percentiles for time taken during rising to stand. Control group subjects (s).

	healthy	week 0	week 1	week 2	week 3	week 4	week 5	week 6
median	2.31	9.14	5.86	4.16	6.43	6.76	3.92	11.77
25th percentile	2.10	9.14	4.47	2.53	3.04	4.55	2.67	7.43
75th percentile	2.63	9.14	6.35	5.11	9.79	7.70	4.95	14.91
interquartile range	*0.53*	*0.00*	*1.88*	*2.58*	*6.75*	*3.15*	*2.28*	*7.49*
5th percentile	1.68	9.14	3.36	2.09	2.69	2.78	1.67	4.13
95th percentile	3.06	9.14	6.74	9.13	10.04	8.45	5.77	15.32
90% range	*1.39*	*0.00*	*3.38*	*7.05*	*7.35*	*5.67*	*4.10*	*11.19*

Table 13.11 Median and percentiles for time taken during rising to stand. Practice group subjects (s).

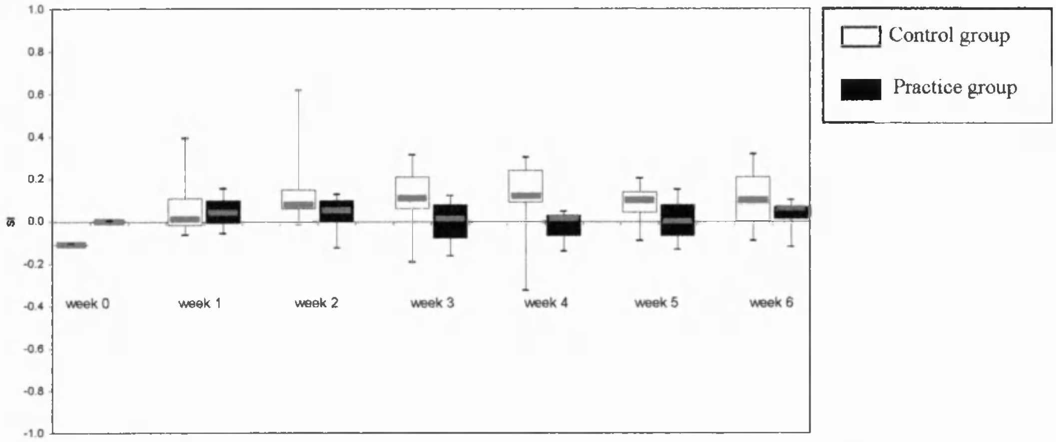


Figure 13.13 Medians, interquartile ranges, and ranges of SI during seat-on phase of rising to stand for control and practice group subjects.

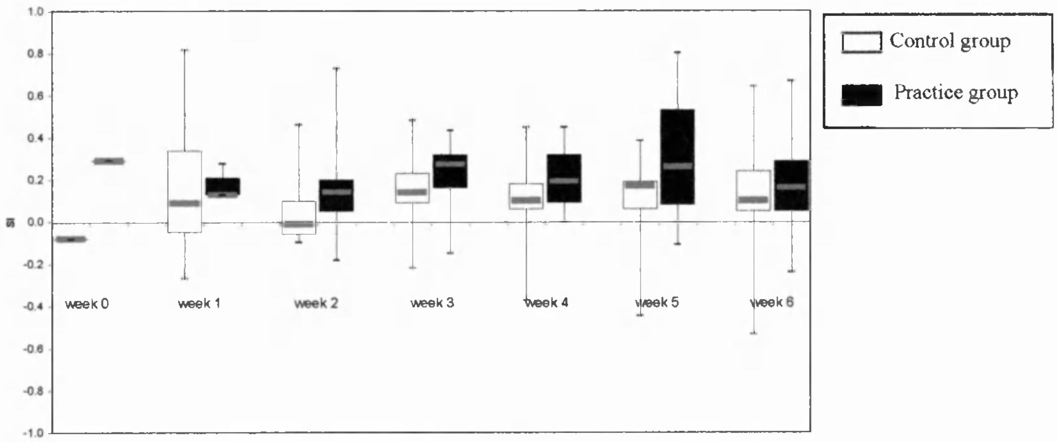


Figure 13.14 Medians, interquartile ranges, and ranges of SI during seat-off phase of rising to stand for control and practice group subjects.

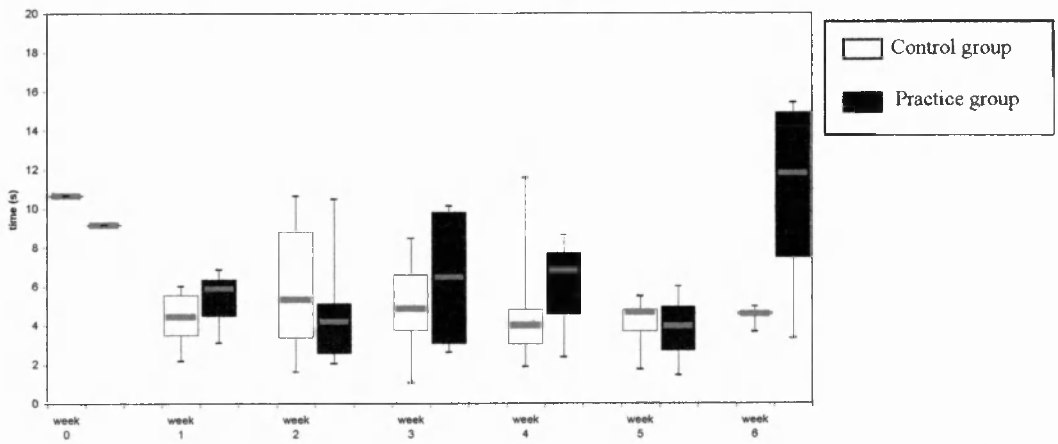


Figure 13.15 Medians, interquartile ranges and ranges of time taken to rise to stand for control and practice group subjects.

Control group versus healthy subjects

Comparing the patient data with the healthy subject data indicates that the control group subjects had a greater asymmetry of weight bearing than the healthy subjects during the seat-on phase in test weeks 2-6. During the seat-off phase the median value of the SI for the control group subjects was greater than that of the healthy subjects during test weeks 3-6. The time taken to rise to stand was notably longer for the control group subjects than for the healthy subjects, throughout all test weeks. The interquartile range and 90% range of the rising to stand data was greater for the control group subjects than for the healthy subjects for all of the reported variables, on all test weeks.

Practice group versus healthy subjects

In contrast to the control group subjects, there was little difference in the median value of the SI during the seat-on phase between the practice group subjects and the healthy subjects. However, the median value of the SI during the seat-off phase for the practice group was higher than that for the healthy subjects during all test weeks, indicating a definite preference for increased weight bearing to the unaffected side during this phase. Similar to the control group, the time taken to rise to stand was longer for the practice group subjects than for the healthy subjects, throughout all test weeks. The interquartile range and 90% range of the rising to stand data was greater for the practice group subjects than for the healthy subjects for all of the reported variables, on all test weeks, with the exception of the seat-off data during week 1.

Control group versus practice group

The data indicates that the control group demonstrated greater asymmetry of weight bearing during the seat-on phase of rising to stand during test weeks 2 – 6, than the practice group. The control group subjects appear to have had a tendency for increased weight bearing on the unaffected side during these test weeks. Although there was substantial overlap between the interquartile ranges and ranges of the SI from the seat-off phase during test weeks 1-6, the median for the practice group was higher than for the control group during all test weeks. This suggests that the practice group subjects had a greater preference for increased weight bearing on the unaffected side than did the control group subjects during this phase. Figure 13.15 demonstrates that there was no observable difference or pattern in the time taken to rise to stand between the practice and control group subjects during test weeks 1-5. During test week 6 the median time taken by the practice group subjects was substantially greater than during other weeks, or than the control group subjects; the low number of practice group subjects tested during week 6 may have been responsible for this anomalous result.

In summary, the control group subjects demonstrated increased weight bearing to the unaffected side during the seat-on phase, but the practice group results were more similar to the healthy subject data. The hemiplegic subjects generally tended to distribute more weight to the unaffected side than to the affected side during the seat-off phase of rising to stand. There were some observable differences between the control and practice group subjects, with the control group demonstrating greater asymmetry of weight bearing to the unaffected side during the seat-on phase, and the practice group exhibiting greater asymmetry of weight bearing to the unaffected side during the seat-off phase. There were large differences between the healthy and hemiplegic subjects for the time taken to rise to stand, with no remarkable differences between the time taken by the control and practice groups.

13.3.3 Effect of discharge and inability to perform on group results

As in the analysis of the tests of standing, the high number of subjects unable to perform rising to stand and the number of subjects discharged had the potential to produce median and percentile results which masked trends in the data. The two methods of analysis (investigating the trends in the results of subjects completing a minimum number of tests and analysing the results from the first and last test from each subject) which were utilised in the exploration of the ability to stand are also appropriate for the analysis of the rising to stand data.

In the analysis of stance, subjects completing 4 or more tests of standing were included in the exploration of the trends in subjects completing a minimum number of tests. To ensure consistency, 4 tests was assigned as the minimum number of tests of rising to stand required to be included in the analysis. This included 47% (n=9) of the control group and 44% (n=4) of the practice group. Figure 13.16, Figure 13.17 and Figure 13.18 illustrate the median, interquartile range and range of the symmetry indices for the two phases of rising to stand and for the time taken to rise to stand for the subjects tested for 4 or more weeks. Figure 13.16 illustrates that there was no observable directional trend in the changes of the mean SI for the seat-on phase over the test sessions. However, the symmetry indices for the practice group subjects can be observed to be generally lower than the symmetry indices for the control group subjects: this suggests that the practice group subjects had greater symmetry than the control group subjects during this phase. This supports the whole-group trend observed previously (Figure 13.13). During the seat-off phase, both the control and practice group subjects distributed more weight to the unaffected side on all test weeks. There was no observable difference between median values for the control group and the practice group. The lack of difference observed differs from the whole group result, where the practice group subjects were observed to have greater asymmetry to the unaffected side than the control group subjects. Unlike the whole-group results, where no remarkable trends were observed in the time taken by the control and practice groups, observing the results from the subjects with 4 or more tests suggests that the time taken by the control and practice group decreased between test 1 and test 4.

As in the whole group results, the practice group appeared to take a longer time during the final test (test 5 in Figure 13.18 and test week 6 in Figure 13.15). Although these results produce slightly different patterns and trends from the whole group results, these were generally small, suggesting that there was little difference between the whole group results and the results of subjects completing more than 4 test weeks. The low number of subjects included in this analysis limits the ability to generalise.

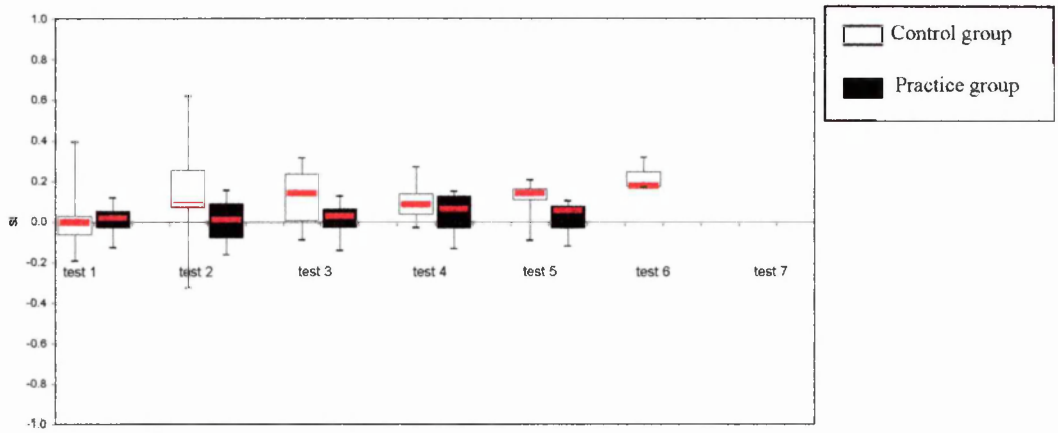


Figure 13.16 Median, interquartile range and range of symmetry of seat-on phase for hemiplegic subjects completing 4 or more tests of rising to stand.

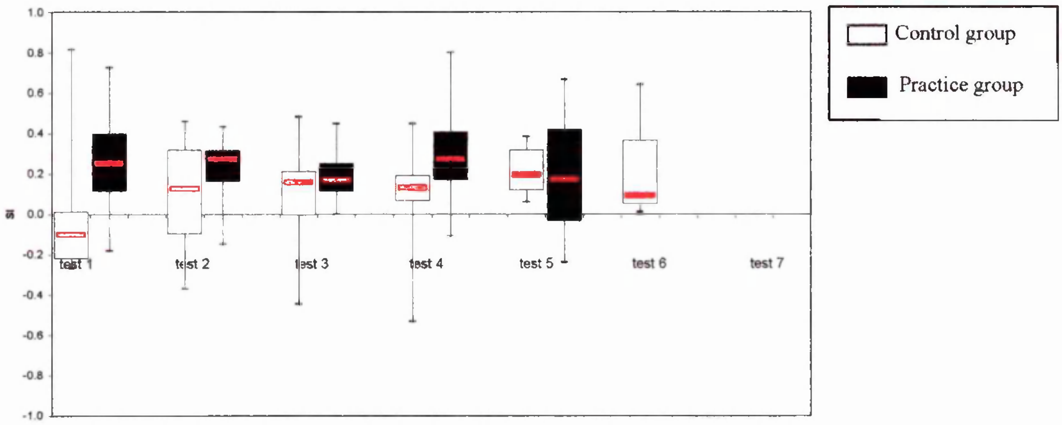


Figure 13.17 Median, interquartile range and range of symmetry of seat-off phase for hemiplegic subjects completing 4 or more tests of rising to stand.

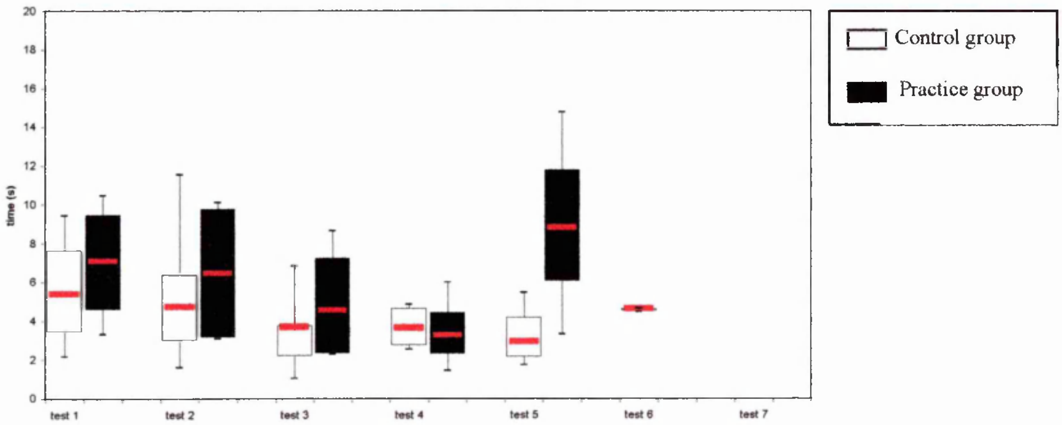


Figure 13.18 Median, interquartile range and range of time taken to rise to stand for hemiplegic subjects completing 4 or more tests.

The second method of investigating trends in the rising to stand data involved determining the outcome variables for the first and last test of each subject. Table 13.12 displays the median and interquartile range of the outcome variables from the first and last test for the control and practice group subjects. These figures demonstrate that both the control group and practice group subjects distributed more weight to the unaffected side in the seat-on phase during the last than during the first test. Additionally, the interquartile range decreased for the last test compared with the first test. There was no change in the median SI during the seat-off phase between the first and last tests for the practice group: in contrast the control group distributed more weight to the unaffected side during the last test. However the magnitude of the asymmetry was less for the control group than for the practice group during the first test. The variation between subjects in the symmetry of the seat-off phase increased from the first to the last test, for both the control and practice groups. The time taken decreased between the first and last test for both control and practice group subjects, although the interquartile range increased for the practice group and not for the control group.

		control			practice		
		seat-on SI	seat-off SI	time (s)	seat-on SI	seat-off SI	time (s)
median	1st test	0.02	-0.07	6.00	0.03	0.15	6.84
	last test	0.12	0.11	3.64	0.06	0.15	4.22
interquartile range	1st test	0.24	0.16	4.57	0.08	0.12	4.36
	last test	0.12	0.35	2.72	0.02	0.20	5.11

Table 13.12 Median and interquartile range for rising to stand variables during subjects' first and last tests.

Thus, despite difficulties with analysis relating to the low and changing number of subjects competing rising to stand in each test week, a number of general trends were observed. During the seat-on phase the practice group subjects appeared to demonstrate greater symmetry of weight bearing than the control group subjects, having a median SI close to that of the healthy subjects on all test weeks. Both the control and practice group subjects demonstrated asymmetrical weight bearing during the seat-off phase, distributing more weight to the unaffected side than to the affected side. There was a relatively large variation between subjects throughout this phase. The time taken to rise to stand by the practice and control group was longer than that of the healthy subjects throughout the test period, and there was considerable variation between subjects.

13.3.4 Classification of ability

Using the definition of 'normal' values determined in the analysis of the sitting data (being equal to the 90% range from the healthy subjects) the proportion of hemiplegic subjects with symmetry during rising to stand and time taken to rise to stand in the normal range was determined. Additionally, the proportion of subjects unable to perform the task was assessed. The proportion of subjects with the SI or time taken falling within the 5^{th} and 95^{th} percentiles of the normal (healthy subject) data for the control and practice group is shown in Table 13.13 - Table 13.15, and in Figure 13.19 - Figure 13.24.

These tables and graphs indicate that there was a low percentage of both control and practice subjects who achieved normal weight distribution during either phase of rising to stand, or normal time to complete the movement. The percentage of practice group subjects achieving normal symmetry values during the seat-on phases was greater than the percentage of control group subjects, while for the seat-off phase and for the time taken the opposite occurred, for all test weeks. However, statistical comparison, using the Chi-squared test, of the ability of the subjects to achieve normal values of weight distribution during the seat-on and seat-off phases and to achieve normal values of time to complete the movement of rising to stand demonstrated that there were no significant differences between the ability of the control and practice group subjects, on any of the test weeks ($Chi^2<0.05$). The Chi-squared values are displayed in Table 13.13 - Table 13.15.

	Control			Practice			
	unable	abnormal	normal	unable	abnormal	normal	*Chi*^{2}
Week 0	95%	5%	0%	89%	0%	11%	*0.272*
Week 1	55%	17%	28%	62%	13%	25%	*0.940*
Week 2	44%	50%	6%	24%	38%	38%	*0.110*
Week 3	35%	53%	12%	33%	50%	17%	*0.954*
Week 4	31%	56%	13%	40%	20%	40%	*0.266*
Week 5	34%	53%	13%	40%	40%	20%	*0.864*
Week 6	41%	42%	17%	20%	60%	20%	*0.689*

Table 13.13 Proportion of control and practice group subjects achieving normal mean symmetry during seat-on phase of rising to stand, and the Chi^2 statistic for the difference between the ability of the control and practice group subjects.

	Control			Practice			
	unable	abnormal	normal	unable	abnormal	normal	*Chi*^{2}
Week 0	95%	0%	5%	89%	11%	0%	*0.272*
Week 1	55%	28%	17%	62%	38%	0%	*0.461*
Week 2	45%	33%	22%	24%	63%	13%	*0.381*
Week 3	35%	53%	12%	33%	67%	0%	*0.651*
Week 4	31%	50%	19%	40%	40%	20%	*0.918*
Week 5	34%	53%	13%	40%	40%	20%	*0.864*
Week 6	37%	27%	36%	20%	80%	0%	*0.117*

Table 13.14 Proportion of control and practice group subjects achieving normal mean symmetry during seat-off phase of rising to stand, and the Chi^2 statistic for the difference between the ability of the control and practice group subjects.

	Control			Practice			
	unable	abnormal	normal	unable	abnormal	normal	*Chi*^{2}
Week 0	95%	5%	0%	89%	11%	0%	*0.575*
Week 1	55%	39%	6%	62%	38%	0%	*0.781*
Week 2	45%	44%	11%	25%	50%	25%	*0.528*
Week 3	35%	53%	12%	33%	50%	17%	*0.954*
Week 4	31%	38%	31%	40%	40%	20%	*0.877*
Week 5	33%	40%	27%	40%	60%	0%	*0.424*
Week 6	36%	64%	0%	20%	80%	0%	*0.513*

Table 13.15 Proportion of control and practice group subjects achieving normal time to rise to stand, and the Chi^2 statistic for the difference between the ability of the control and practice group subjects.

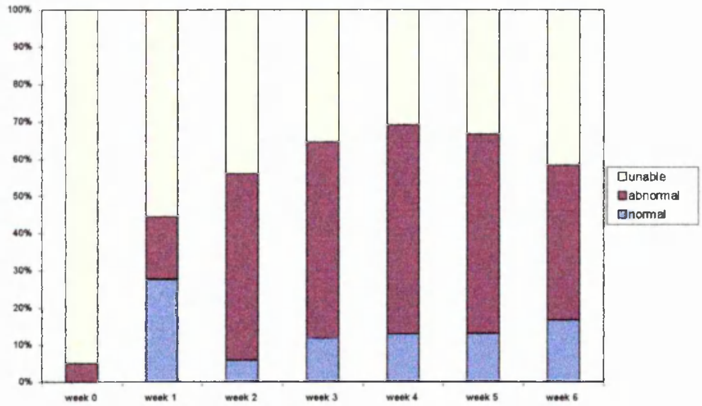


Figure 13.19
Proportion of control group subjects achieving normal weight distribution during seat-on phase of rising to stand on different test weeks

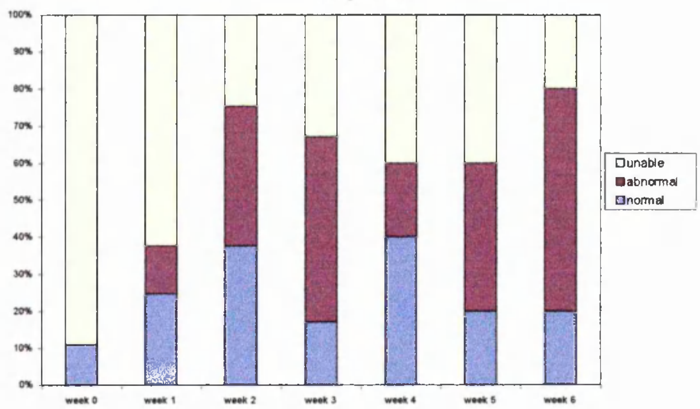


Figure 13.20
Proportion of practice group subjects achieving normal weight distribution during seat-on phase of rising to stand on different test weeks

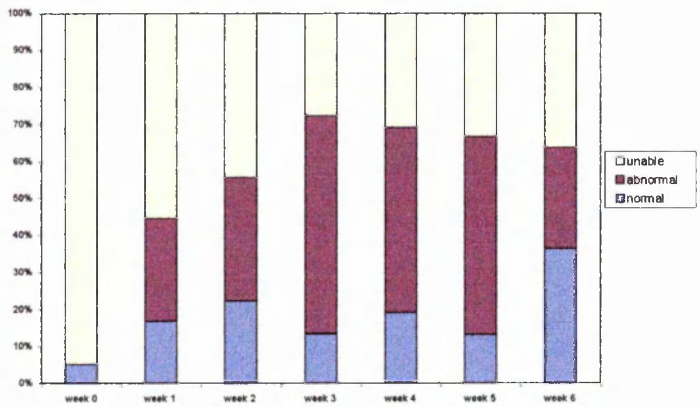


Figure 13.21
Proportion of control group subjects achieving normal weight distribution during seat-off phase of rising to stand on different test weeks

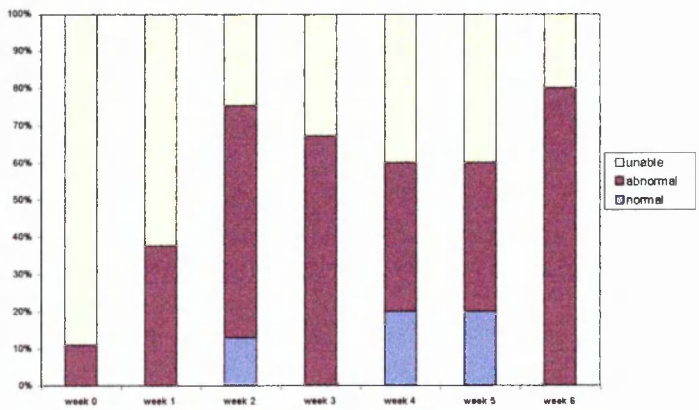


Figure 13.22
Proportion of practice group subjects achieving normal weight distribution during seat-off phase of rising to stand on different test weeks

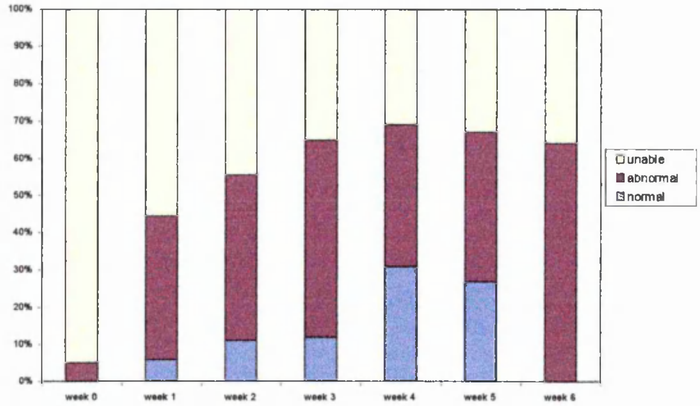


Figure 13.23 Proportion of control group subjects achieving normal time to complete rising to stand on different test weeks

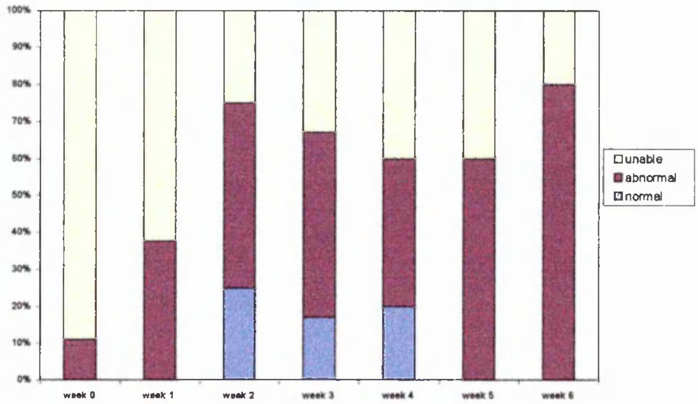


Figure 13.24 Proportion of practice group subjects achieving normal time to complete rising to stand on different test weeks

The number of control and practice group subjects whose ability to rise to stand changed, relative to the 'normal', between their first and last test day is shown in Table 13.16 - Table 13.18. These results demonstrate that very few subjects were able to achieve rising to stand during the first test, but that 68% (47%+16%+5%) of the control group subjects and 77% (33%+33%+11%) of the practice group subjects did achieve rising to stand during the test period. Comparing the results for the control and practice group subjects for each of the measured variables demonstrates that there was little difference in the proportion of subjects from the two groups with changes between the first and last measure. For all the variables the greatest proportion of subjects were unable to perform rising to stand at the initial test, and were with out the normal range during their performance on their last test. The only exception to this was for the seat-on phase for the practice group subjects where an equal proportion of the subjects changed from unable to normal weight distribution as from unable to abnormal weight distribution.

Ability at final measurement

Initial ability	Control unable	Control abnormal	Control normal	Practice unable	Practice abnormal	Practice normal
Unable	6 (32%)	9 (47%)	3 (16%)	2 (22%)	3 (33%)	3 (33%)
Abnormal	0 (0%)	1 (5%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
Normal	0 (0%)	0 (0%)	0 (0%)	0 (0%)	1 (11%)	0 (0%)

Table 13.16 Number (and percentage) of control and practice group subjects with ability to achieve normal symmetry of weight distribution in seat-on phase changing between the initial and final measurement.

Ability at final measurement

Initial ability	Control unable	Control abnormal	Control normal	Practice Unable	Practice abnormal	Practice normal
Unable	6 (32%)	7 (37%)	5 (26%)	2 (22%)	5 (56%)	1 (11%)
Abnormal	0 (0%)	0 (0%)	0 (0%)	0 (0%)	1 (11%)	0 (0%)
Normal	0 (0%)	0 (0%)	1 (5%)	0 (0%)	0 (0%)	0 (0%)

Table 13.17 Number (and percentage) of control and practice group subjects with ability to achieve normal symmetry of weight distribution in seat-off phase changing between the initial and final measurement.

Ability at final measurement

Initial ability	Control unable	Control abnormal	Control normal	Practice Unable	Practice abnormal	Practice normal
Unable	6 (32%)	8 (42%)	4 (21%)	2 (22%)	5 (56%)	1 (11%)
Abnormal	0 (0%)	1 (5%)	0 (0%)	0 (0%)	0 (0%)	1 (11%)
Normal	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)

Table 13.18 Number (and percentage) of control and practice group subjects with ability to achieve normal time during rising to stand changing between the initial and final measurement.

14. Results: Sitting down

14.1 Raw data and analysis

The symmetry index was determined for each test of sitting down. Examples of the SI during sitting down for a young, elderly, and hemiplegic subject are provided in Figure 14.1, Figure 14.2 and Figure 14.3. In addition to displaying the SI, these graphs display the point where seat-on occurred and the points where the movement was identified to start and stop.

14.1.1 Calculation of phases

Sitting down was divided into a seat-off (phase 1) and a seat-on (phase 2) phase. In order to ensure that the division of the data into two phases, and the identification of the start and end of the movement, were repeatable these were computed from the raw data. Movement was defined as occurring if the total vertical force varied more than plus or minus 2 standard deviations from the mean vertical force determined during rest. The process of dividing the movement into phases was similar to the process of dividing the movement of rising to stand into phases.

The mean SI during the seat-off and seat-on phases were calculated, and the mean time to sitting down was determined.

Seat-off phase

The start of movement was determined by calculating the mean and standard deviation of the total vertical force over 1 second of data collection immediately prior to the command for the subject to start moving. When the vertical force became greater than the mean resting vertical force by + 2 standard deviations, or became less than the mean resting vertical force by – 2 standard deviations, it was assumed that movement was occurring. To ensure that this was not an anomalous change, due to postural sway, the movement was not assumed to have started until the vertical force had remained out of the 'normal' range for at least 8 out of 10 consecutive samples.

The end of this phase was defined as the moment in time when seat-on occurred. This point occurred when the vertical force recorded by the seat section became greater than zero. (To allow for the slight noise within the measurement system, this point was, in fact, determined as occurring when the force through the seat became greater than 1N.)

Seat-on phase

This phase started at seat-on.

The end of movement was determined by calculating the mean and standard deviation of the total vertical force over 1 second of data collection, at a point 2 seconds after the recording ceased. When the vertical force was within the range defined by the mean $\pm$ 2 standard deviations from the mean, it was assumed that movement had ceased. To ensure that this was not an anomalous finding, as the vertical force moved through the range, the movement was not assumed to have stopped until the vertical force remained within the 'normal' range for at least 8 out of 10 consecutive samples.

As in the observation of the raw data for rising to stand, variation in the SI over the period of data collection was seen for sitting down. The study by Durward (1994), previously discussed in section 13.1, investigated sitting down in addition to rising to stand. The conclusions drawn by Durward (1994), pertaining to the reproducibility of results, referred to the results for sitting down as well as those for rising to stand. The arguments given in section 13.1, stating that the mean SI was an appropriate measure of outcome in the analysis of rising to stand, therefore also apply to the analysis of data relating to sitting down. Rising to stand and sitting down are related functions, and the use of the same outcome variables for the exploration of the symmetry of weight distribution during these two functions was therefore supported. Hence, the mean SI for the seat-off and seat-on phases and the time taken to sit down were selected and determined as the outcome variables in the analysis of sitting down.

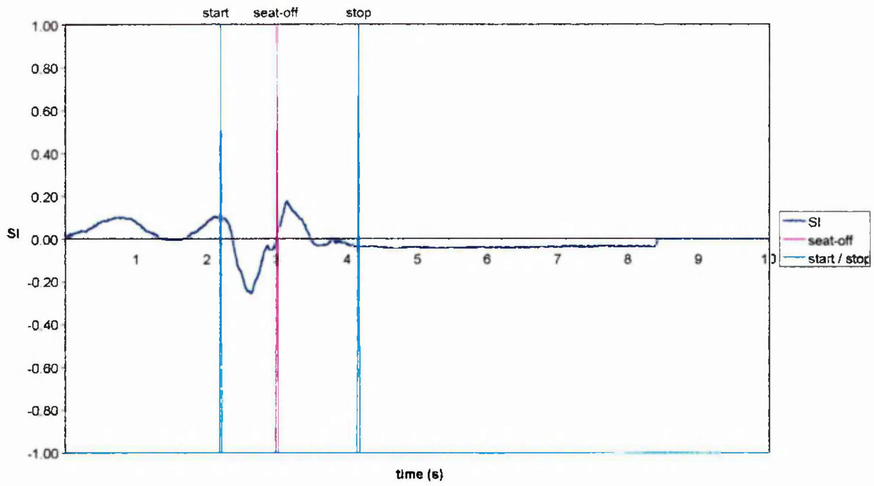


Figure 14.1 Symmetry of sitting down. Young healthy subject.

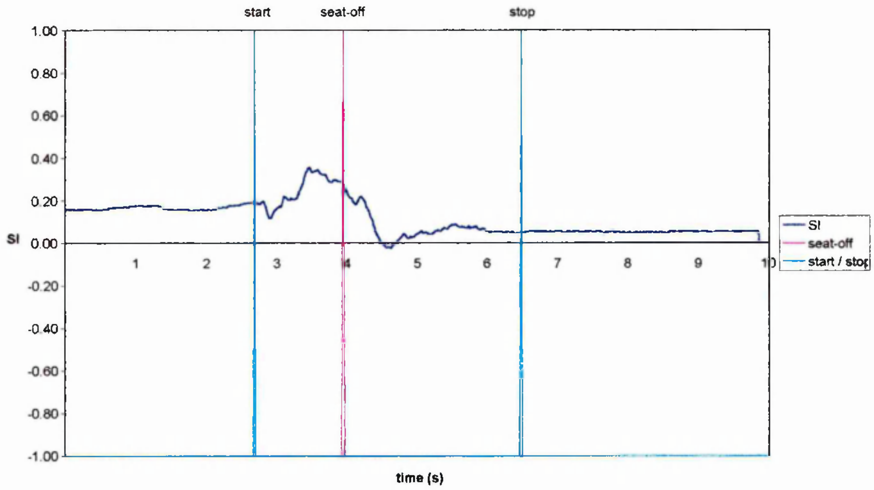


Figure 14.2 Symmetry of sitting down. Elderly healthy subject.

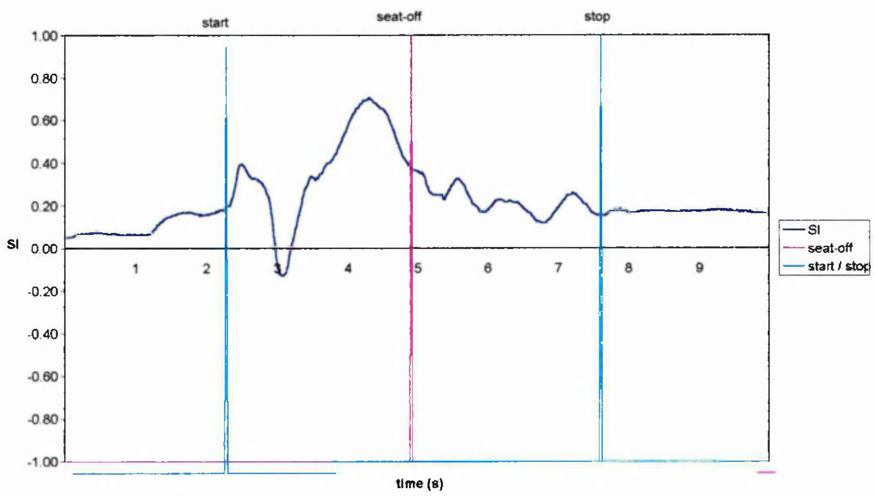


Figure 14.3 Symmetry of sitting down. Hemiplegic subject.

14.2 Healthy subjects

The percentage close agreement for each of the two phases of the 3 trials of sitting down for the young and elderly healthy subjects is provided in Table 14.1. The variation between the 3 repeated measures for the seat-off phase was less than that of the seat-on phase for the young (90% of differences less than 0.09 for the seat-on SI and less than 0.14 for the seat-off SI) and elderly (90% of differences less than 0.10 for the seat-on SI and less than 0.24 for the seat-off SI) subjects. This was the opposite to the variation found during repeated trials of rising to stand, where the variation during the seat-off phase was greater than that during the seat-on phase. The variation between the repeated measures for the seat-off phase was comparable to the variation between repeated tests of standing (90% of the differences in SI during standing were less than 0.07 and 0.10 for the young and elderly respectively; and during the seat-off phase of rising to stand were 0.09 and 0.10 for the young and elderly respectively). The variation in the repeated measures of the time taken was relatively low (90% within 1.0s for the young and 1.3s for the elderly), and was similar to the variation in the repeated measures of the time taken during rising to stand (90% within 1.0s for the young and 0.9s for the elderly).

		PCA (80%)	PCA (90%)	PCA (95%)	PCA (100%)
SEAT-OFF PHASE (SI)	*Young*	0.07	0.09	0.10	0.14
	Elderly	0.09	0.10	0.14	0.17
SEAT-ON PHASE (SI)	*Young*	0.09	0.14	0.27	0.32
	Elderly	0.15	0.24	0.28	0.53
TIME (S)	*Young*	0.7	1.0	1.4	1.7
	Elderly	1.1	1.3	1.7	2.1

Table 14.1 PCA for reported variable from 3 repeated trials of sitting down; young and elderly healthy subjects.

Figure 14.4, Figure 14.5 and Figure 14.6 illustrate the variation between the SI for the seat-off and seat-on phases and between the time taken during repeated tests of sitting down for the young healthy subjects; the variation between the repeated trials for the elderly subjects was similar in profile. The greater magnitude of variation in repeated measures of the seat-on phase, which accounted for the increased PCA values can be observed in Figure 14.5.

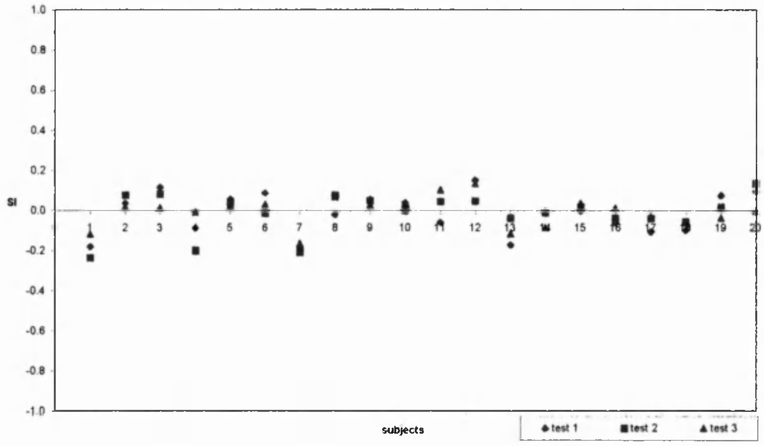


Figure 14.4 Mean symmetry index from 3 trials of sitting down: seat-off phase. Young healthy subjects.

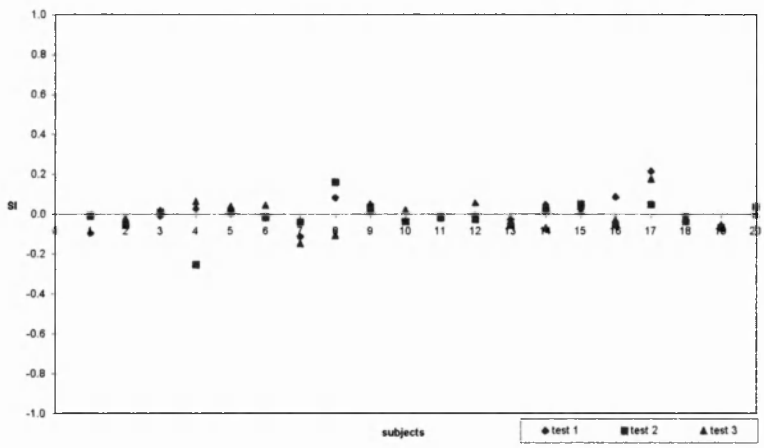


Figure 14.5 Mean symmetry index from 3 trials of sitting down: seat-on phase. Young healthy subjects.

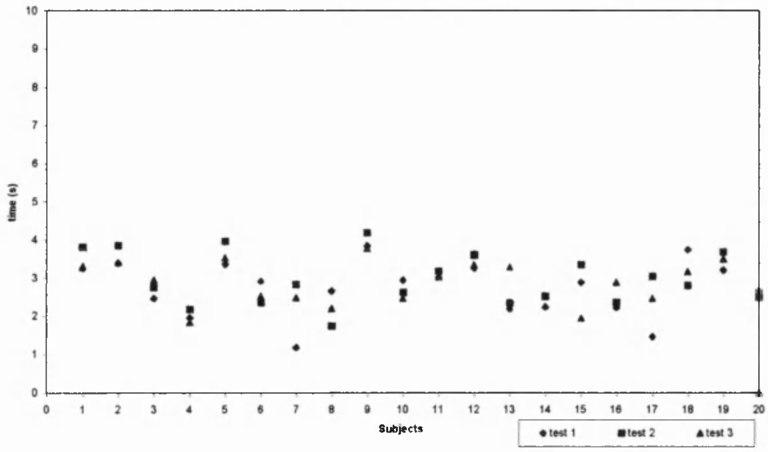


Figure 14.6 Mean time taken to sit down from 3 trials of sitting down. Young healthy subjects.

90% of the differences between repeated measures of the SI during the seat-off phase were less than 0.09 for the young subjects, and the mean of the repeated measures of the SI during the seat-off phase for 90% of the young subjects was in a range of 0.29. For the elderly subjects these values were 0.10 and 0.35 respectively. For the seat-on phase these values were 0.14 and 0.12 respectively for the young subjects; and 0.24 and 0.22 respectively for the elderly subjects. For the time taken these equivalent values were 1.0 and 1.5 for the young subjects and 1.3 and 1.3 for the elderly subjects. Thus, the variation between repeated measures was less than the variation between the group results for the seat-off phase: this was the same pattern as was observed for the differences between repeated measures and between subjects during quiet stance. However, for the SI during the seat-on phase and for the time taken to sit down the variation between repeated measures was similar to the variation between the group results. The mean of the 3 repeated measures for the symmetry of weight distribution during the two sitting down phases and the time taken to sit down was used in the remaining analysis.

The distribution of the mean variables during sitting down for the young and elderly healthy subjects are displayed in Figure 14.7 - Figure 14.12. The median values and 5^{th}, 25^{th}, 75^{th}, and 95^{th} percentiles for each of the variables for the young and elderly healthy subjects are displayed in Table 14.2. The histograms indicate that the distribution of the mean SI did not exhibit skew and that the distribution was around 0 for the seat-off phase and seat-on phase for the young subjects. However, observation of the histogram and data for the seat-off phase for the elderly subjects indicates that there was a slight skew in the data, suggesting that the elderly subjects distribute more weight to the left side during the seat-on phase. During the seat-on phase the distribution of the symmetry data for the elderly subjects exhibited no skew and was centred on 0. During the seat-off phase, the median SI was 0.01 for the young subjects and 0.04 for the elderly subjects. This was a similar difference as was found in the median values of the SI during quiet stance. As in the case for the standing data, despite the slight difference in the variation of the seat-off data for the young and elderly subjects, the variation between the two groups was similar, with both groups demonstrating relatively low interquartile and 90% ranges. There was little observable difference between the interquartile and 90% range for the symmetry data during the two phase of sitting down, for either the young or elderly subjects. This suggests that the variation between subjects was similar during both phases of sitting down. This differs from the variation found during rising to stand, where the variation during the seat-off phase was found to be greater than the variation during the seat-on phase.

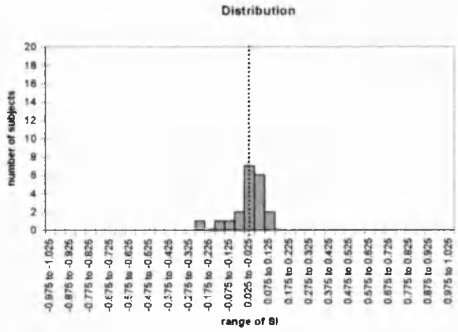


Figure 14.7 Distribution of mean symmetry index during seat-off phase of sitting down in young healthy subjects.

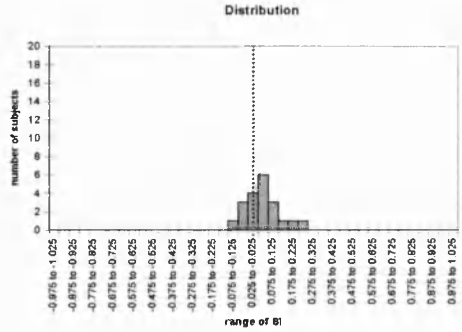


Figure 14.8 Distribution of mean symmetry index for seat-off phase of sitting down in elderly healthy subjects.

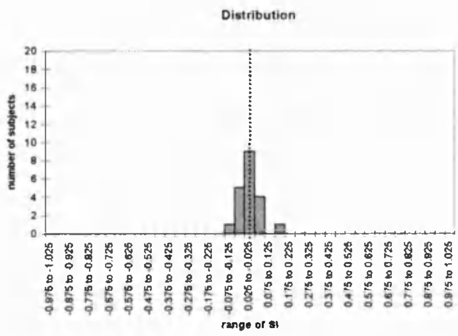


Figure 14.9 Distribution of mean symmetry index during seat-on phase of sitting down in young healthy subjects.

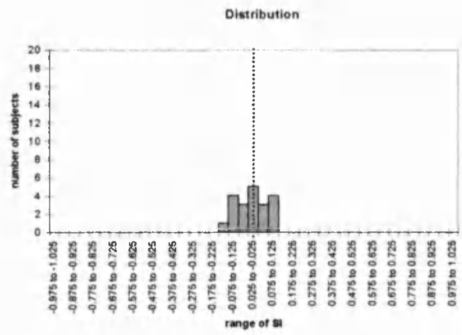


Figure 14.10 Distribution of mean symmetry index during seat-on phase of sitting down in elderly healthy subjects.

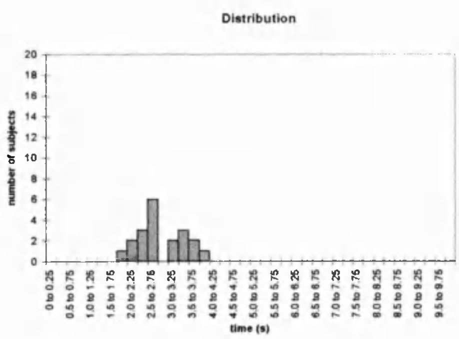


Figure 14.11 Distribution of mean time taken to sit down in young healthy subjects.

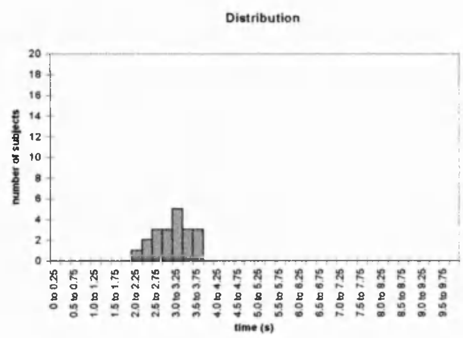


Figure 14.12 Distribution of mean time taken to sit down in elderly healthy subjects.

Comparing the distribution and ranges of the time taken to sit down by the young and elderly subjects demonstrated that there was little difference between the groups. The median value for the time taken was slightly greater for the elderly subjects than for the young subjects, but the percentile values were very similar for the two groups.

	Mean SI seat-off phase (SI)		Mean SI seat-on phase (SI)		Mean time to sit down (s)	
	young	elderly	young	elderly	young	elderly
median	0.007	0.036	0.000	0.003	2.693	3.010
25^{th} percentile	-0.018	-0.023	-0.039	-0.062	2.470	2.598
75^{th} percentile	0.033	0.078	0.022	0.060	3.412	3.307
interquartile range	0.052	0.100	0.061	0.122	0.942	0.708
5^{th} percentile	-0.148	-0.051	-0.065	-0.107	2.152	2.264
95^{th} percentile	0.088	0.204	0.050	0.101	3.629	3.573
90% range	0.237	0.255	0.115	0.208	1.478	1.309

Table 14.2 Medians and percentiles for symmetry and time data during sitting down. Young and elderly healthy subjects.

Multiple regression was carried out to investigate the association between the symmetry and time variables and the independent variables (gender, age, age group, height, body mass, lower-leg length, dominant hand). The R-squared and significance values are listed in Table 14.3 - Table 14.5. The definition of significant association previously identified (section 10.2) was used. There was a significant association between the mean SI during the seat-on phase and the dominant hand ($R^2 = 0.209$). The regression equation indicated that subjects with left dominance had increased weight-bearing to the left during the seat-on phase of sitting down and vice versa (with X = 0 when the dominant hand is left and X = 1 when the dominant hand is right). However, despite the apparent strength of this association, care had to be taken in interpreting this finding, as 37 (92%) of the 40 healthy subjects were right-handed. No significant association was found between the outcome variables and any of the other independent variables.

independent variable	age	age group	gender	mass	height	lower leg length	dominant hand
R^2	0.084	0.077	0.015	0.001	0.019	0.019	0.000
t_m	0.069	0.084	0.445	0.821	0.393	0.402	0.978
t_c	0.313	0.220	0.152	0.971	0.357	0.354	0.737
gradient							
constant							

Table 14.3 R-squared and significance values for association between mean SI during seat-off phase of sitting down and independent variables.

independent variable	age	age group	gender	mass	height	lower leg length	dominant hand
R^2	0.000	0.000	0.112	0.009	0.050	0.035	0.209
t_m	0.948	0.981	0.035	0.567	0.165	0.251	0.003
t_c	0.821	0.889	0.169	0.537	0.160	0.242	0.006
gradient							-0.109
constant							0.097

Table 14.4 R-squared and significance values for association between mean SI during seat-on phase of sitting down and independent variables.

independent variable	age	age group	gender	mass	height	lower leg length	dominant hand
R^2	0.120	0.014	0.087	0.013	0.000	0.003	0.011
t_m	0.386	0.465	0.065	0.487	0.976	0.745	0.519
t_c	0.000	0.000	0.000	0.000	0.065	0.035	0.000
gradient							
constant							

Table 14.5 R-squared and significance values for association between time taken to sit down and independent variables

14.3 Hemiplegic subjects

14.3.1 Baseline measurement (week 0)

None of the hemiplegic subjects were able to sit down independently at the time of the baseline measurement. This therefore prevented the investigation of the distribution of the symmetry and time variables prior to the start of the intervention.

14.3.2 Control and practice groups

As in the exploration of the rising to stand data, comparison between the control group and practice group results for sitting down was carried out with the use of descriptive statistics. The median, percentiles and interquartile and 90% ranges of the symmetry and time data are shown in Table 14.6 to Table 14.11. The median and quartile ranges of the symmetry data are shown graphically in Figure 14.13, Figure 14.14 and Figure 14.15.

Control group versus healthy subjects

The control group subjects demonstrated greater asymmetry of weight distribution than the healthy subjects during the seat-off phase on all test weeks. The median SI was greater for the control group than for the healthy subjects, on all test weeks. The degree of asymmetry during these test weeks was relatively large: the median value from the control group subjects was greater than the 95th percentile for the healthy subjects during test weeks 2-6. During the seat-on phase the differences between the control group and healthy subjects were not as distinct as during the seat-off phase. The control group median SI for the seat-off phase was slightly lower than that of healthy subjects during test weeks 1 and 2, and slightly higher during weeks 3-6. The time taken to sit down by the control group subjects was longer than that taken by the healthy subjects on all test weeks.

	Healthy	week 0	week 1	week 2	week 3	week 4	week 5	week 6
median	0.02		0.04	0.17	0.26	0.17	0.19	0.13
25th percentile	-0.02		0.00	0.11	0.23	0.04	0.17	0.03
75th percentile	0.05		0.16	0.30	0.35	0.26	0.19	0.33
interquartile range	0.07		*0.16*	*0.19*	*0.13*	*0.22*	*0.02*	*0.30*
5th percentile	-0.12		-0.03	0.06	0.02	-0.02	0.08	-0.01
95th percentile	0.14		0.41	0.55	0.59	0.63	0.52	0.59
90% range	0.25		*0.44*	*0.49*	*0.58*	*0.65*	*0.44*	*0.61*

Table 14.6 Median and percentiles for SI during seat-off phase of sitting down. Control group subjects (SI).

	Healthy	week 0	week 1	week 2	week 3	week 4	week 5	week 6
median	0.02		0.28	0.26	0.35	0.18	0.18	-0.11
25th percentile	-0.02		0.09	0.17	0.32	0.01	0.04	-0.15
75th percentile	0.05		0.46	0.26	0.41	0.32	0.28	0.20
interquartile range	0.07		*0.37*	*0.09*	*0.09*	*0.31*	*0.24*	*0.35*
5th percentile	-0.12		0.05	-0.08	0.30	-0.13	-0.06	-0.18
95th percentile	0.14		0.49	0.34	0.46	0.43	0.36	0.45
90% range	0.25		*0.43*	*0.42*	*0.16*	*0.56*	*0.43*	*0.63*

Table 14.7 Median and percentiles for SI during seat-off phase of sitting down. Practice group subjects (SI).

	Healthy	week 0	week 1	week 2	week 3	week 4	week 5	week 6
median	0.00		-0.05	-0.02	0.18	0.18	0.08	0.05
25th percentile	-0.04		-0.13	-0.15	0.13	0.05	0.04	-0.04
75th percentile	0.03		0.01	0.09	0.27	0.20	0.09	0.08
interquartile range	0.08		*0.14*	*0.23*	*0.14*	*0.15*	*0.05*	*0.11*
5th percentile	-0.10		-0.19	-0.29	0.02	-0.06	0.04	-0.22
95th percentile	0.10		0.04	0.12	0.31	0.49	0.15	0.10
90% range	0.20		*0.23*	*0.40*	*0.30*	*0.55*	*0.11*	*0.31*

Table 14.8 Median and percentiles for SI during seat-on phase of sitting down. Control group subjects (SI).

	Healthy	week 0	week 1	week 2	week 3	week 4	week 5	week 6
median	0.00		-0.01	0.07	0.11	-0.24	-0.08	-0.01
25th percentile	-0.04		-0.05	-0.03	0.04	-0.25	-0.14	-0.08
75th percentile	0.03		0.10	0.11	0.23	-0.15	-0.08	0.02
interquartile range	0.08		*0.14*	*0.14*	*0.19*	*0.09*	*0.06*	*0.10*
5th percentile	-0.10		-0.06	-0.16	-0.01	-0.25	-0.19	-0.13
95th percentile	0.10		0.25	0.15	0.33	-0.09	-0.08	0.04
90% range	0.20		*0.31*	*0.31*	*0.35*	*0.16*	*0.11*	*0.17*

Table 14.9 Median and percentiles for SI during seat-on phase of sitting down. Practice group subjects (SI).

	Healthy	week 0	week 1	week 2	week 3	week 4	week 5	week 6
median	2.92		3.83	2.82	3.50	4.00	3.40	4.23
25th percentile	2.57		3.36	2.26	2.32	2.44	2.84	4.13
75th percentile	3.41		4.20	3.34	3.98	4.80	4.26	4.71
interquartile range	0.85		*0.84*	*1.09*	*1.66*	*2.36*	*1.42*	*0.58*
5th percentile	2.20		2.93	1.86	2.08	2.12	2.73	3.95
95th percentile	3.62		4.39	4.16	4.43	5.78	5.96	5.77
90% range	1.42		*1.46*	*2.31*	*2.35*	*3.66*	*3.23*	*1.83*

Table 14.10 Medians and percentiles for time taken to sit down. Control group subjects (s).

	Healthy	week 0	week 1	week 2	week 3	week 4	week 5	week 6
median	2.92		4.33	3.72	3.86	4.28	4.14	2.82
25th percentile	2.57		4.00	3.64	3.23	3.84	3.64	2.23
75th percentile	3.41		4.58	3.92	4.76	5.62	4.23	3.47
interquartile range	0.85		*0.58*	*0.28*	*1.53*	*1.78*	*0.59*	*1.24*
5th percentile	2.20		3.22	3.13	2.73	3.49	3.24	1.76
95th percentile	3.62		5.14	4.19	5.48	6.69	4.30	3.99
90% range	1.42		*1.92*	*1.06*	*2.75*	*3.20*	*1.06*	*2.23*

Table 14.11 Medians and percentiles for time taken to sit down. Practice group subjects (s).

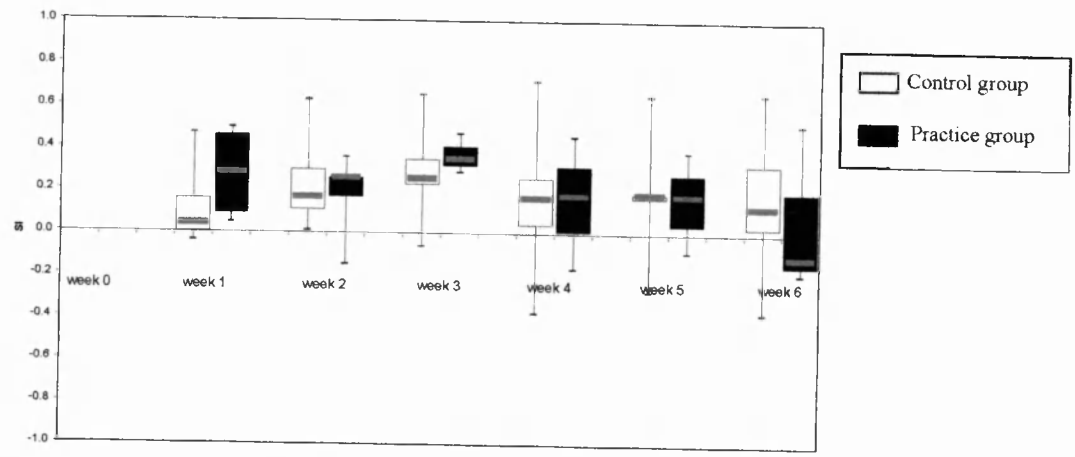


Figure 14.13 Medians, interquartile ranges and ranges of SI during seat-off phase of sitting down for control and practice group subjects.

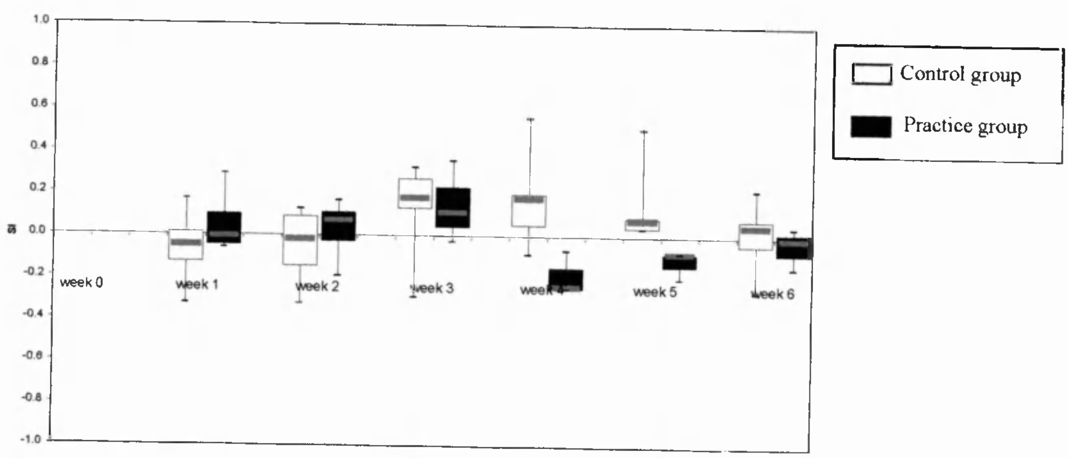


Figure 14.14 Medians, interquartile ranges and ranges of SI during seat-on phase of sitting down for control and practice group subjects.

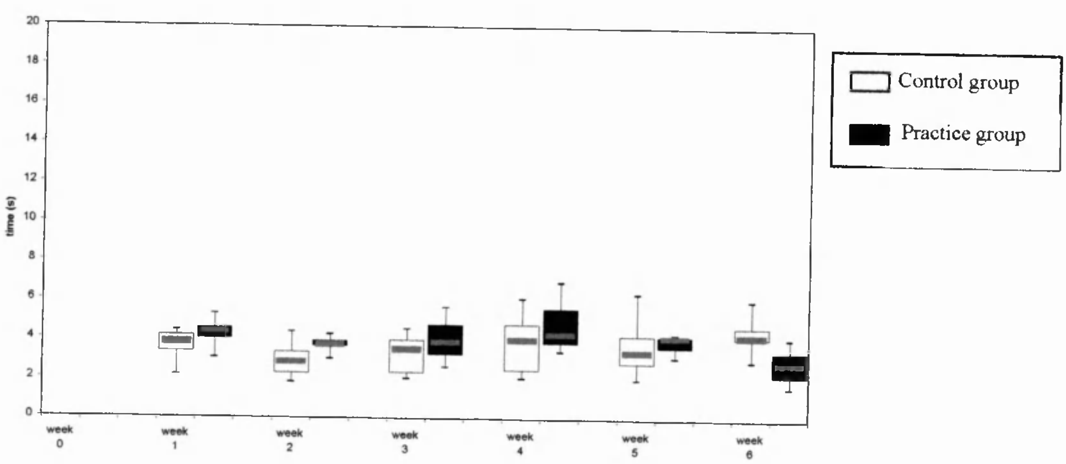


Figure 14.15 Medians, interquartile ranges and ranges of time taken to sit down for control and practice group subjects.

Practice group versus healthy subjects

As for the control group, the practice group subjects exhibited greater asymmetry of weight distribution than the healthy subjects during the seat-off phase of sitting down. The median SI for the seat-off phase of sitting down for the practice group was greater than that for the healthy subjects on all test weeks, with the exception of test week 6. During weeks 1 to 5 the magnitude of the weight distribution to the unaffected side was relatively high, with the median value from the practice group subjects being higher than the 95^{th} percentile of the healthy subjects. The differences between the practice group and healthy subjects were not as distinct during the seat-on phase. During the seat-on phase, the practice group median symmetry value was similar to that of the healthy subjects during week 1, but was greater during weeks 2 and 3, and smaller during weeks 4-6. The increased asymmetry, indicated by the lower SI during test weeks 4-6, suggests that the practice group distributed more weight to the affected side than to the unaffected side during these weeks. Increased weight distribution to the affected side was not observed during the analysis of the results pertaining to sitting, standing or rising to stand. The interquartile and 90% ranges of the values from the seat-on phase of sitting down for the practice group subjects were relatively similar to those of the healthy subjects. This suggests that the variation between the practice group subjects was similar to the variation between the healthy subjects, for this variable. This contrasts with the data which indicates that for sitting, standing, the two phases of rising to stand and the seat-off phase of sitting down the variation between the hemiplegic subjects was greater than that of the healthy subjects. As for the control group, the time taken to sit down by the practice group tended to be longer than that taken by the healthy subjects, with the practice group median time taken being larger than that of the healthy subjects on all test weeks.

Control group versus practice group

During the seat-off phase, both the control group and practice group demonstrated increased weight bearing to the unaffected side. No trends or differences between the control group and practice group could be observed for the SI during the seat-off phase. The SI during the seat-on phase was similar for the control group and practice group during test week 1, 2 and 3; however, during weeks 4, 5 and 6 the control group had increased weight bearing to the unaffected side while the practice group demonstrated increased weight bearing to the affected side. There were no observable trends or differences in the time taken to sit down by the control group and practice group subjects. Figure 14.15 demonstrates that the time taken to sit down by the hemiplegic subjects tended to be longer than that taken by the healthy subjects. Comparing the data relating to the time to sit down and with that relating to the time to rise to stand demonstrates that the variation between subjects during sitting down was considerably less than the variation between subjects during rising to stand.

Thus the hemiplegic subjects tended to distribute more weight to the unaffected side than to the affected during the seat-off phase of sitting down. There were less remarkable differences between the hemiplegic subjects and the healthy subjects during the seat-on phase, although – during weeks 4, 5 and 6 – the control group had increased weight bearing to the unaffected side, while the practice group demonstrated increased weight bearing to the affected side. The hemiplegic subjects took longer to sit down than the healthy subjects, although the variation in the time taken between the hemiplegic subjects was similar to that between the healthy subjects.

14.3.3 Effect of discharge and inability to perform on group results

As in the analysis of the tests of standing and rising to stand, the high number of subjects unable to perform rising to stand and the number of subjects discharged had the potential to produce median and percentile results which masked trends in the data. Although two methods of analysis were used in the exploration of the standing and rising to stand data, the first of these methods was unsuitable for use with the sitting down data. The first methodology involved the exploration of the trends in the data of subjects who completed a stipulated minimum number of tests. For the analysis of standing and rising to stand the minimum number of tests was defined as 4. However only 22% (n=2) of the practice group subjects achieved 4 or more tests of sitting down. This group size was not sufficiently large to allow for analysis of group trends. Only 33% (n=3) of the practice group achieved 3 tests or more; this remained too small for group analysis. It was therefore not possible to explore the trends in the symmetry or time data over a number of test weeks for subjects completing a number of consecutive tests of sitting down.

Since the second method of analysis included all subjects who achieved sitting down during the test period, this method of analysis included a greater number of subjects. The median and interquartile range for the first and last test of sitting down, for the control and practice group of subjects, were determined and are listed in Table 14.12.

		Control			practice		
		seat-off SI	seat-on SI	time (s)	seat-off SI	seat-on SI	time (s)
median	1st test	0.09	0.02	2.86	0.28	-0.01	4.09
	last test	0.19	0.10	3.90	0.22	0.06	3.68
interquartile range	1st test	0.24	0.16	1.12	0.40	0.28	1.11
	last test	0.12	0.11	1.41	0.37	0.09	1.00

Table 14.12 Median and interquartile range for sitting down variables during subjects' first and last tests.

The median symmetry during the seat-off phase of sitting down was greater than that of the healthy subjects for both the control and practice groups during both the first and last test. This result was consistent with the observations made from the whole group data. At the first test, the median symmetry value for the seat-on phase was similar to that of the healthy subjects for both the control and practice group subjects. However, at the final test both the control and practice group subjects distribute more weight to the unaffected side. This finding does not agree with the observation of data from the whole group, which indicated that the practice group subjects distributed greater weight to the affected side during the later tests. The time taken to sit down during the first test was longer for the practice group than for the control group, but during the last test was slightly longer for the control group. The whole group results were unable to distinguish any trends in the time taken to sit down.

Thus, the low number of hemiplegic subjects limited the ability to analyse trends in the sitting down data. The analysis of the first and last tests for the subjects able to sit down produced data that could lead to slightly different conclusions than indicated by the whole group results. The difficulties in analysing and drawing conclusions from these results emphasised the limitation in the data relating to the lack of ability of hemiplegic subjects and the discharge of subjects from the trial.

14.3.4 Classification of ability

The analysis of the symmetry and time variables was limited due to the lack of ability of the hemiplegic subjects. Classifying the subjects according to their ability or inability to perform sitting down and to achieve "normal" symmetry and time variables when able was therefore a useful method of analysis. The ability of the hemiplegic subjects was determined using the methodology previously described. The proportion of control and practice group subjects able to sit down, and able to do so with the SI or time taken falling between the 5th and 95th percentiles of the normal (healthy subject) data is displayed in Table 14.13 – Table 14.15, and in Figure 14.16 – Figure 14.21.

	Control			Practice			
	unable	abnormal	normal	unable	abnormal	normal	*Chi²*
Week 0	100%	0%	0%	100%	0%	0%	-
Week 1	61%	17%	22%	50%	25%	25%	*0.845*
Week 2	44%	28%	28%	37%	63%	0%	*0.134*
Week 3	41%	47%	12%	50%	50%	0%	*0.673*
Week 4	37%	50%	13%	40%	60%	0%	*0.703*
Week 5	33%	60%	7%	40%	40%	20%	*0.610*
Week 6	37%	45%	18%	40%	40%	20%	*0.979*

Table 14.13 Proportion of control and practice group subjects achieving normal mean symmetry during seat-off phase of sitting down, and the Chi² statistic for the difference between the ability of the control and practice group subjects.

	Control			Practice			
	unable	abnormal	normal	unable	abnormal	normal	*Chi²*
Week 0	100%	0%	0%	100%	0%	0%	-
Week 1	61%	22%	17%	49%	13%	38%	*0.489*
Week 2	44%	28%	28%	38%	38%	24%	*0.883*
Week 3	41%	41%	18%	50%	33%	17%	*0.927*
Week 4	38%	38%	24%	40%	40%	20%	*0.974*
Week 5	33%	40%	27%	40%	20%	40%	*0.705*
Week 6	36%	29%	36%	40%	20%	40%	*0.953*

Table 14.14 Proportion of control and practice group subjects achieving normal mean symmetry during seat-on phase of sitting down, and the Chi² statistic for the difference between the ability of the control and practice group subjects.

	Control			Practice			
	unable	abnormal	normal	unable	abnormal	normal	*Chi²*
Week 0	100%	0%	0%	100%	0%	0%	-
Week 1	61%	17%	22%	49%	38%	13%	*0.489*
Week 2	44%	28%	28%	37%	50%	13%	*0.493*
Week 3	42%	29%	29%	50%	33%	17%	*0.877*
Week 4	38%	38%	24%	40%	40%	20%	*0.974*
Week 5	33%	40%	27%	40%	40%	20%	*0.944*
Week 6	36%	55%	9%	40%	40%	20%	*0.785*

Table 14.15 Proportion of control and practice group subjects achieving normal time to sit down, and the Chi² statistic for the difference between the ability of the control and practice group subjects.

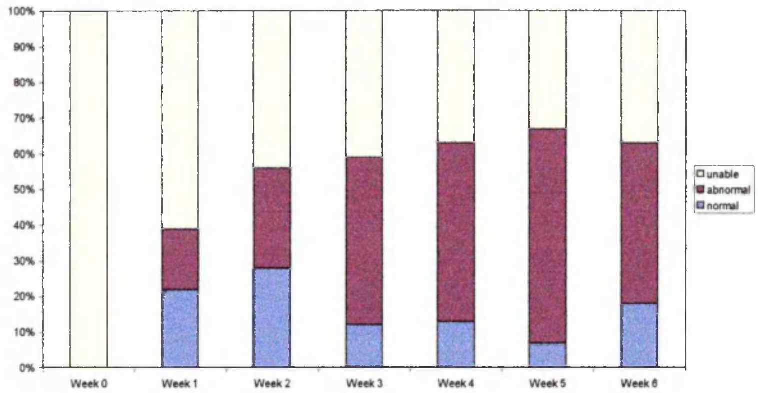


Figure 14.16 Proportion of control group subjects achieving normal weight distribution during seat-off phase of sitting down on different test weeks.

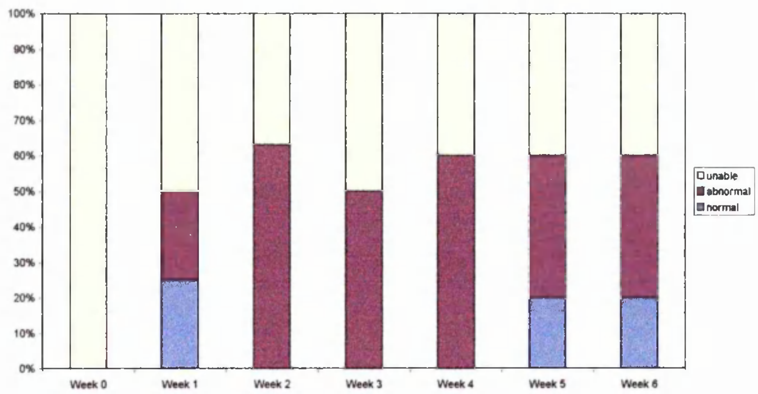


Figure 14.17 Proportion of practice group subjects achieving normal weight distribution during seat-off phase of sitting down on different test weeks.

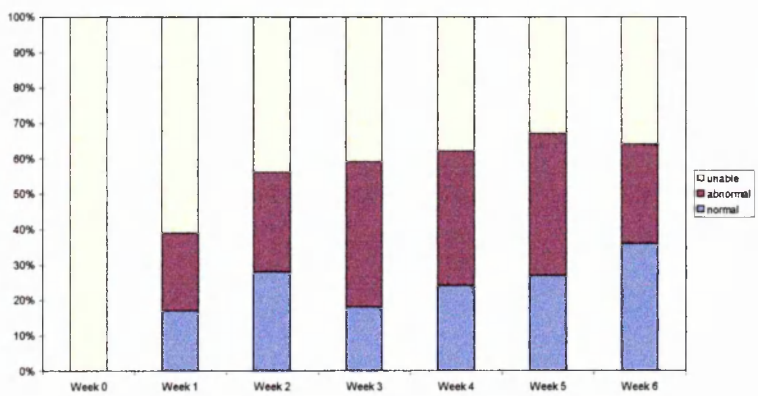


Figure 14.18 Proportion of control group subjects achieving normal weight distribution during seat-on phase of sitting down on different test weeks.

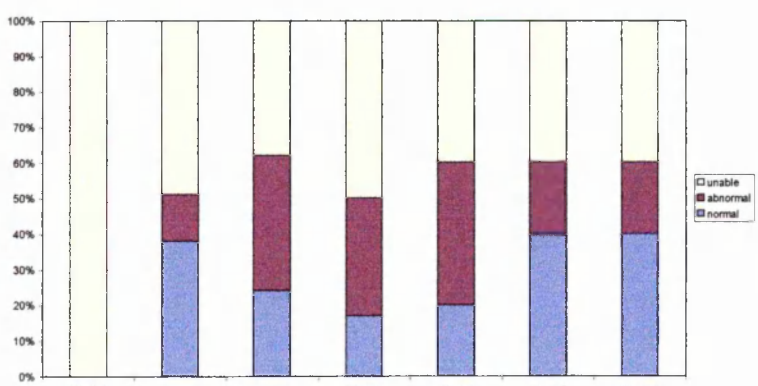


Figure 14.19 Proportion of practice group subjects achieving normal weight distribution during seat-on phase of sitting down on different test weeks.

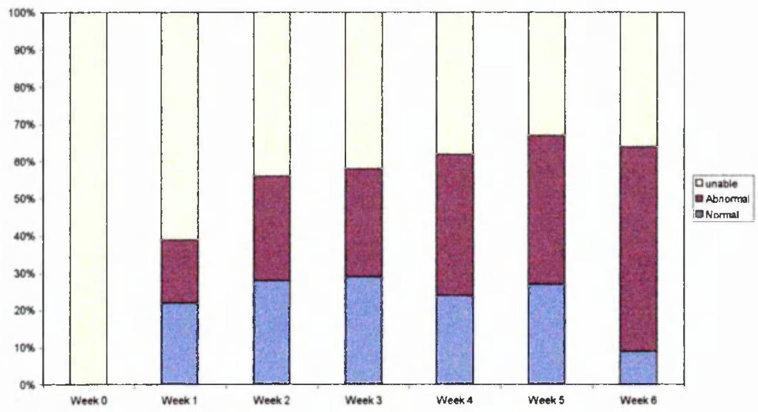


Figure 14.20 Proportion of control group subjects achieving normal time to complete sitting down on different test weeks.

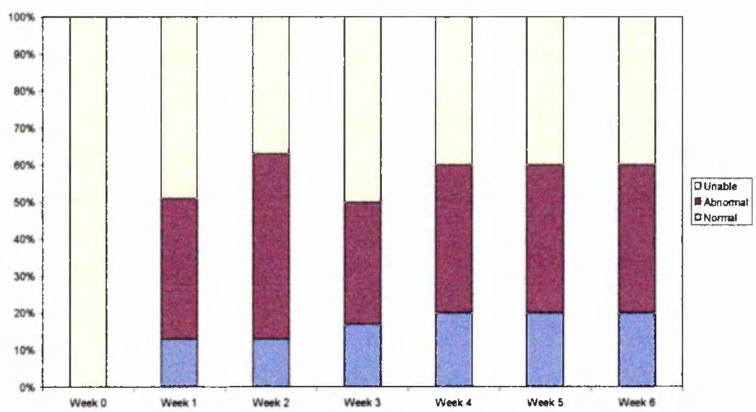


Figure 14.21 Proportion of practice group subjects achieving normal time to complete sitting down on different test weeks.

The high proportion of hemiplegic subjects who remained unable to perform sitting down throughout the test period is highlighted by the graphs illustrating ability. The proportion of subjects unable to perform sitting down decreased substantially between week 0 and week 1 for both the control and practice groups. After this initial change there was little further change in the proportion of practice group subjects unable to perform sitting down, while the proportion of control group subjects unable to perform sitting down decreased slightly throughout the subsequent test weeks. The proportion of subjects with the mean SI within normal limits during the seat-off phase was very low throughout the test period for both the control (maximum 28%) and practice (maximum 25%) groups. The number of subjects achieving normal weight distribution during the seat-on phase was greater than during the seat-off phase, for both the control (maximum 36%) and practice (maximum 40%) groups. The proportion of subjects achieving normal time to sit down was also very low (control maximum 29%; practice maximum 20%). There was no observable trend in the proportion of subjects with normal symmetry of weight distribution during the seat-off or the seat-on phase, or with normal time taken to sit down, for the control or practice group subjects over the test weeks. Statistical comparison, using the Chi-squared test, of the outcome variables from the control and practice groups confirmed the observable lack of difference between the groups, demonstrating that there was no significant difference. The Chi-squared values are displayed in Table 14.13 – Table 14.15.

The data pertaining to the proportion of subjects with outcome variables changing between the first and last measurement is displayed in Table 14.16, Table 14.17 and Table 14.18. These tables highlight that, for each of the outcome variables for both the control and the practice group, approximately 30% of the subjects did not achieve the ability to sit down during the trial period; between approximately 30% and 60% became able to sit down but did not perform this within the normal range; and only between approximately 10% and 30% achieved the ability to perform sitting down within the normal limits.

Ability at final measurement

		Control			Practice		
		unable	abnormal	normal	unable	abnormal	normal
Initial ability	Unable	6 (32%)	11 (58%)	2 (11%)	3 (33%)	5 (56%)	1 (11%)
	Abnormal	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
	Normal	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)

Table 14.16 Number (and percentage) of control and practice group subjects with ability to achieve normal symmetry of weight distribution in seat-off phase changing between the initial and final measurement.

Ability at final measurement

		Control			Practice		
		unable	abnormal	normal	Unable	abnormal	normal
Initial ability	Unable	6 (32%)	8 (42%)	5 (26%)	3 (33%)	3 (33%)	3 (33%)
	Abnormal	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
	Normal	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)

Table 14.17 Number (and percentage) of control and practice group subjects with ability to achieve normal symmetry of weight distribution in seat-on phase changing between the initial and final measurement.

Ability at final measurement

		Control			Practice		
		unable	abnormal	normal	Unable	abnormal	normal
Initial ability	Unable	6 (32%)	9 (47%)	4 (21%)	3 (33%)	5 (56%)	1 (11%)
	Abnormal	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
	Normal	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)

Table 14.18 Number (and percentage) of control and practice group subjects with ability to achieve normal time during sitting down changing between the initial and final measurement.

15. Results: Reaching to the same side

15.1 Raw data and analysis

The symmetry index was determined for each test of reaching to the same side. Examples of the SI during reaching to the same side for a young, elderly, and hemiplegic subject are provided in Figure 15.1, Figure 15.2 and Figure 15.3. In addition to displaying the SI, these graphs display the point where the SI reaches its peak and the points where the movement was identified to start and stop.

Since measurements of the symmetry of weight distribution during reaching to the same side have not previously been identified in the literature, it was initially necessary to ensure that the movement of reaching produced a distinct and reproducible pattern. It was also essential to identify the pertinent outcome measures for the analysis of the movement. In order to allow detailed exploration of the pattern of movement from different subjects a valid and reliable method for the objective identification of the start and end of the movement was required. The following sections define the method of identifying the start and end of the movement of reaching to the same side, discuss the exploration of the pattern of movement and identify the outcome variables that were selected to reflect the changes in the SI during reaching to the same side.

15.1.1 Identification of start and end of movement

The start and end of the reaching movement were determined using derivations of the formulae used to determine the start and end of rising to stand and sitting down. Whereas the start and end of rising to stand and sitting down were determined from the vertical force data, the start and end of reaching were determined from the SI data. The start of movement was determined by calculating the mean and standard deviation of the total SI over 1 second of data collection immediately prior to the command for the subject to start moving. When the SI became greater than the mean resting SI by + 2 standard deviations, or became less than the mean resting SI by – 2 standard deviations, it was assumed that movement was occurring. To ensure that this was not an anomalous change, due to postural sway, the movement was not assumed to have started until the SI had remained out of the 'normal' range for at least 8 out of 10 consecutive samples.

The end of movement was determined by calculating the mean and standard deviation of the total SI over 1 second of data collection, at a point 2 seconds after the subject was observed to stop moving. When the SI was within the range defined by the mean $\pm$ 2 standard deviations from the mean, it was assumed that movement had ceased. To ensure that this was not an anomalous finding, as the SI moved through the range, the movement was not assumed to have stopped until the SI remained within the 'normal' range for at least 8 out of 10 consecutive samples.

15.1.2 Pattern of movement

Since measurements of symmetry of weight distribution during reaching have not previously been reported in the literature, it was necessary to ensure that this movement produced a distinct and reproducible pattern. The start and end of movement were determined for all the healthy subjects, and the data from each individual subject converted to a scale with 100 data points rather than a time scale. The use of the 100 data point scale allowed the direct comparison of the pattern of movement from the healthy subjects, without the influence of the speed or total time of the movement. The mean and standard deviations of the pattern of movement for the healthy subjects were derived from each subject's 100 data points, and plotted graphically. Figure 15.4 shows the graph for the young healthy subjects; the pattern for the elderly subjects was similar. There was a consistent pattern of movement, with a small degree of variation between healthy subjects. Figure 15.1, Figure 15.2 and Figure 15.3 illustrate the pattern of movement for individual subjects. The absence of the smoothing effect that occurs in Figure 15.4, due to the use of the mean SI, provides a more detailed illustration of the pattern of movement for individual subjects. The pattern that occurred started with a SI close to zero, which then increased to a peak, before returning and remaining at a point close to zero.

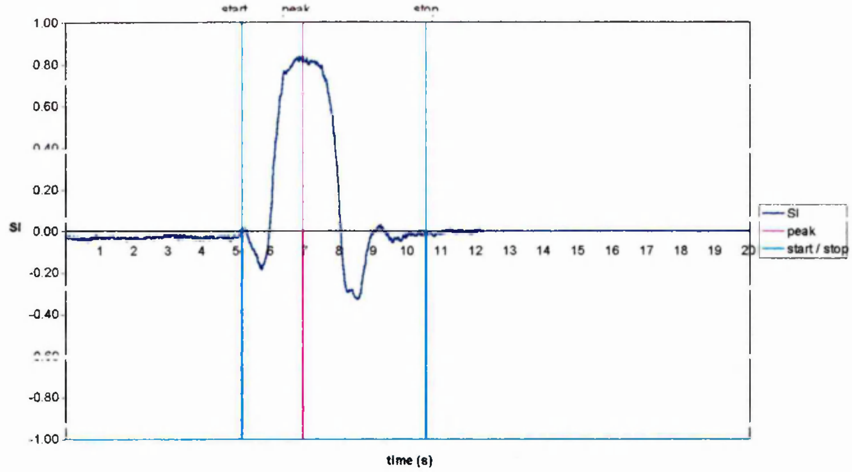


Figure 15.1 Symmetry index during reaching to the same side. Young healthy subject.

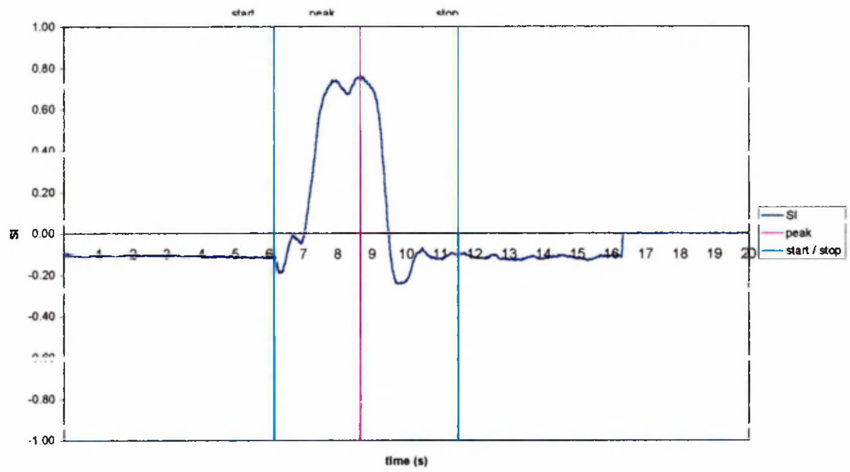


Figure 15.2 Symmetry index during reaching to the same side. Elderly healthy subject.

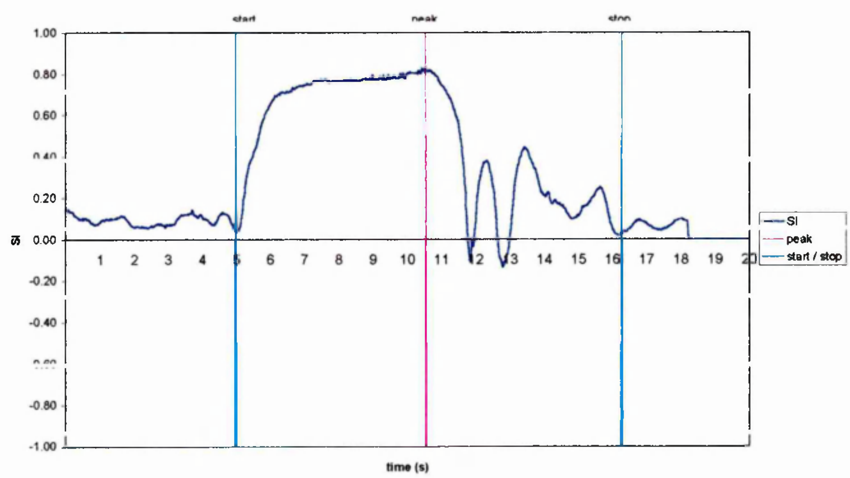


Figure 15.3 Symmetry index during reaching to the same (unaffected) side. Hemiplegic subject.

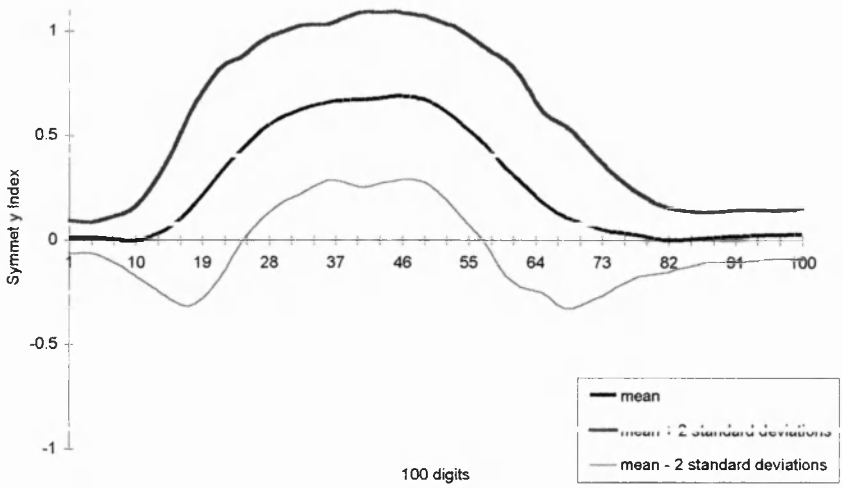


Figure 15.4 Mean pattern of symmetry index during reaching to the same side. Young healthy subjects.

15.1.3 Selection of outcome variables

The movement of reaching to the same side and the subsequent information derived from the SI from each test was fundamentally different from the analysis of the postures and movements of sitting, standing, rising to stand and sitting down. As was outlined in section 8.3, sitting, standing, rising to stand and sitting down can be classified as symmetrical tasks. Hence the analysis of the data pertaining to these functions principally involved the exploration of the mean SI over the time period of the task (chapters 11-14). The mean SI during sitting, standing, rising to stand and sitting down provided information pertaining to the degree of symmetry of weight distribution during each task. In contrast, the aim of the task of reaching to the same side was to achieve maximal weight transference. Weight transference involves the movement of the COP away from the midline (symmetrical) position toward the limits of the BOS (asymmetrical position). Thus the goal of reaching to the same side was to achieve maximal *asymmetry*. An additional goal of the reaching task was to return to "normal" quiet sitting after the completion of the movement.

The pattern of movement found to be described during reaching to the same side started with a SI close to zero, which then increased to a peak, before returning and remaining at a point close to zero. From the knowledge of the biomechanics of the movement of reaching and from the exploration of the SI data collected during reaching, it was assumed that the peak SI that occurred during reaching reflected the maximal asymmetry achieved during the task. Thus the peak SI during the movement of reaching to the same side was selected as an outcome variable. It is assumed that the peak SI was a direct measure of the magnitude of the weight transference occurring during reaching to the same side.

A secondary aim of the movement of reaching to the same side was to return to quiet sitting following the weight transference. As in the analysis of quiet sitting and quiet standing, sitting after reaching was assumed to be a "quiet" posture. Subsequently the mean SI during a period of quiet sitting after the cessation of the reaching movement was assumed to be a pertinent outcome variable. The mean SI during sitting after reaching was defined as the mean SI over the 1 second following the end of movement.

In addition to the symmetry variables, the time taken to execute the movement was investigated. Timed movements have previously been proposed to be potential indicators of functional ability in patients with stroke (Wade et al, 1985a; Durward, 1994).

Hence the outcome variables selected for the analysis of reaching to the same side were the peak SI, the mean SI during sitting after reaching, and the time taken to reach to the same side.

15.2 Healthy subjects

The percentage close agreement for each of the three outcome variables of the 3 trials of reaching to the same side for the young and elderly subjects are provided in Table 15.1.

		PCA (80%)	PCA (90%)	PCA (95%)	PCA (100%)
PEAK SI	*Young*	0.06	0.07	0.08	0.11
	Elderly	0.06	0.10	0.11	0.23
MEAN SI AFTER REACHING	*Young*	0.05	0.06	0.07	0.12
	Elderly	0.07	0.08	0.09	0.14
TIME (S)	*Young*	3.25	3.75	4.5	5.75
	Elderly	3.0	4.5	5.0	7.5

Table 15.1 PCA for reported variables from 3 repeated trials of reaching to the same side; young and elderly healthy subjects.

The variation between the 3 repeated measures of the peak SI during reaching to the same side was very low. 90% of the differences between the repeated measures were less than 0.07 for the young subjects and 0.10 for the elderly subjects. The variation between these values was less than the variation between repeated measures of quiet sitting (during quiet sitting, 90% of the differences were less than 0.08 and less than 0.14 for young and elderly subjects respectively). The variation between the 3 repeated measures of the mean SI during sitting after reaching was also low, with the maximum variation between 90% of the repeated measures being less than 0.06 for the young and 0.08 for the elderly subjects. This was lower than the variation between repeated measures of quiet sitting. 90% of the differences between the repeated measures of the time taken to reach to the same side are less than 4.5s. Although this appears relatively high, compared with values of less than 1s during repeated measures of the time taken to rise to stand, the magnitude of these differences has to be considered relative to the time taken to reach.

The variation between the 3 repeated measures of reaching to the same side for the peak SI, the mean SI during sitting after reaching and for the time taken are displayed graphically in Figure 15.5, Figure 15.6 and Figure 15.7. These graphs display the data from the elderly healthy subjects; the pattern of results from the young healthy subjects was similar. The small degree of variation between repeated measures of the peak SI during reaching to the same side and the mean SI during sitting after reaching to the same side can be observed in Figure 15.5 and Figure 15.6. Figure 15.7 demonstrates that the variation in the time taken between repeated tests of reaching to the same side was relatively large compared to the time taken to reach.

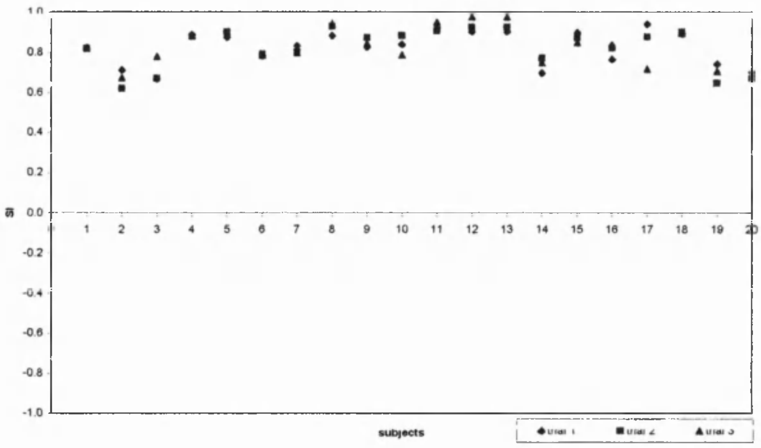


Figure 15.5 Peak symmetry index from 3 trials of reaching to the same side. Elderly healthy subjects.

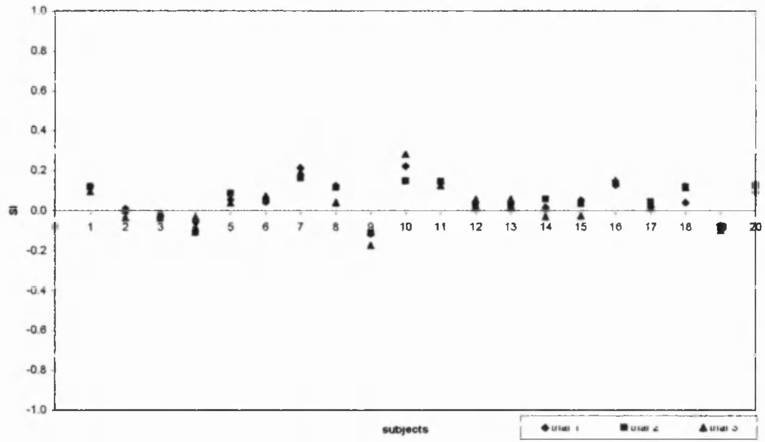


Figure 15.6 Mean symmetry index during sitting after 3 trials of reaching to the same side. Elderly healthy subjects.

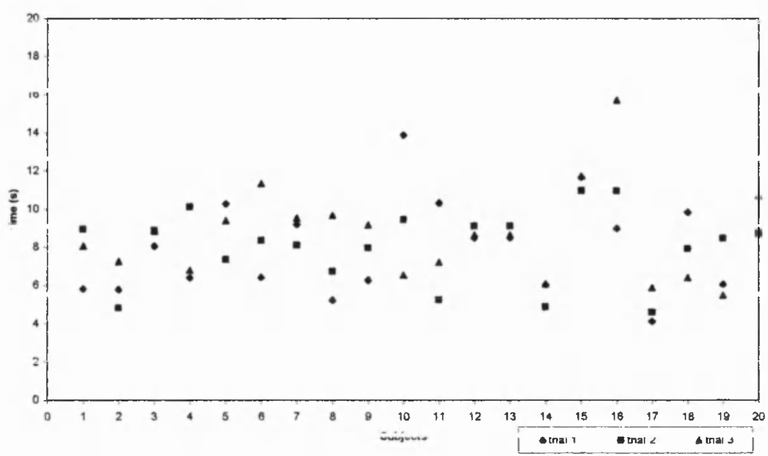


Figure 15.7 Mean time taken during 3 trials of reaching to the same side. Elderly healthy subjects.

The mean value for the 3 repeated measures of the peak SI fell within a range of 0.19 for 90% of the young healthy subjects, and within a range of 0.25 for the elderly healthy subjects. The mean value for the 3 repeated measures of the mean SI during sitting after reaching fell within a range of 0.13 for 90% of the young healthy subjects, and within a range of 0.28 for 90% of the elderly healthy subjects. Comparing these values with the maximum difference between the repeated measures demonstrated by 90% of the healthy subjects (0.07 and 0.10 for the peak SI and 0.06 and 0.08 for the mean SI during sitting after reaching, for the young and elderly subjects respectively) indicates that the variation between the subjects was greater than the variation between repeated measures. The variation between repeated measures and the variation between the subjects for the time taken to reach was similar, with 90% of the mean times taken to reach being within a range of 3.4s and 90% of the differences between repeated measures being less than 3.75s for the young subjects. For the elderly subjects these values were 5.9s and 4.5s respectively.

The mean of the outcome variables for the 3 tests of reaching to the same side were determined and reported for all subsequent analysis.

The distributions of the mean variables for reaching to the same side for the young and elderly healthy subjects are displayed in Figure 15.8 to Figure 15.13. The median values and the 5th, 25th, 75th and 95th percentiles for the young and elderly subjects are shown in Table 15.2. The distribution of the peak SI during reaching to the same side occurred very close to the upper limits of the SI scale. The distribution for both the young and elderly healthy subjects was fairly normal, although the tail of the curves extend at the left end and not at the right. The nature of the SI scale prevents the tail of the distribution curve extending upward (to the right). The median values, interquartile and 90% range for the peak of reaching to the same side were similar for the young and elderly subjects.

	Peak SI during reaching (SI)		**Mean SI after reaching (SI)**		**Mean time to reach (s)**	
	young	**elderly**	**young**	**elderly**	**young**	**elderly**
median	0.852	0.841	0.023	0.046	6.847	8.317
25th percentile	0.802	0.776	0.003	0.009	6.352	7.105
75th percentile	0.897	0.894	0.051	0.114	7.002	8.955
interquartile range	0.095	0.118	0.048	0.105	0.650	1.850
5th percentile	0.759	0.688	-0.044	-0.087	5.401	5.607
95th percentile	0.946	0.935	0.083	0.192	8.847	11.468
90% range	0.187	0.247	0.127	0.279	3.446	5.861

Table 15.2 Medians and percentiles for reaching to the same side. Young and elderly healthy subjects.

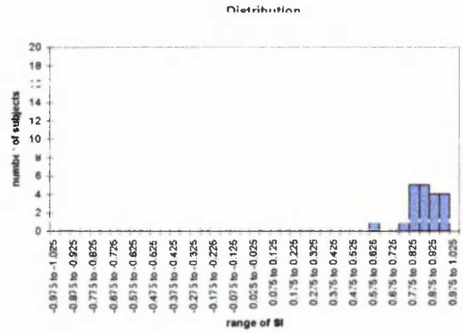


Figure 15.8 Distribution of peak symmetry index during reaching to the same side for young healthy subjects.

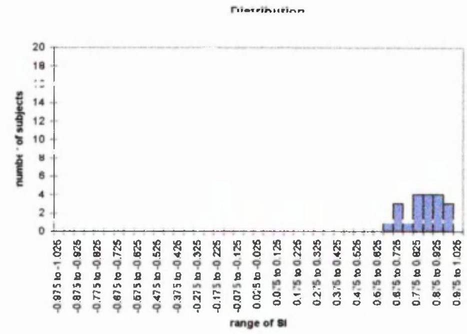


Figure 15.9 Distribution of peak symmetry index during reaching to the same side for elderly healthy subjects.

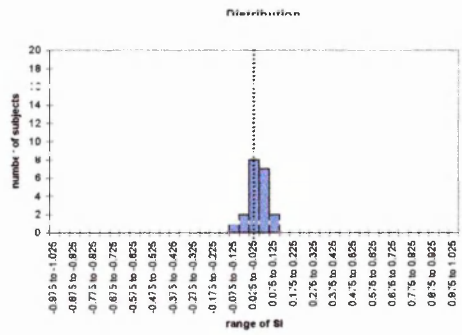


Figure 15.10 Distribution of mean symmetry index after reaching to the same side for young healthy subjects.

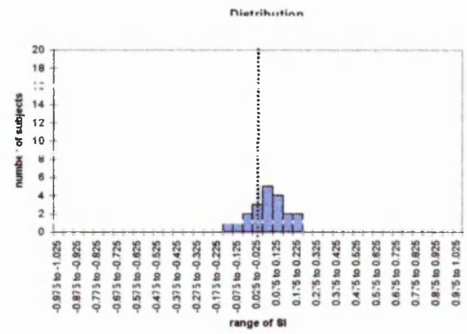


Figure 15.11 Distribution of mean symmetry index after reaching to the same side for elderly healthy subjects.

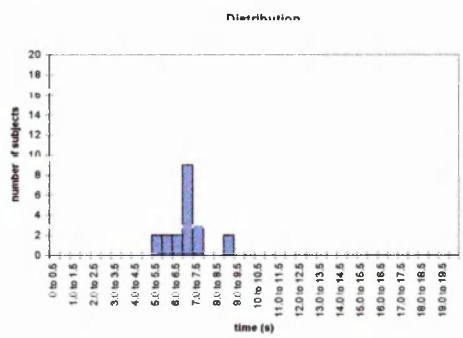


Figure 15.12 Distribution of time taken to reach to the same side for young healthy subjects.

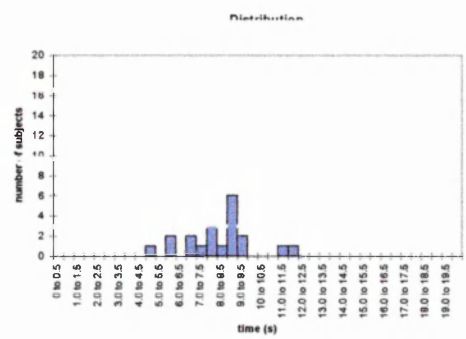


Figure 15.13 Distribution of time taken to reach to the same side for elderly healthy subjects.

The distribution of the mean SI during the period of sitting after reaching to the same side indicated that the distribution was not centred on 0, but was higher than 0. This observation was confirmed by the median and percentile values. For both the young and elderly subjects the 25th percentile remained greater than 0, although the 5th

percentile was less than 0. This was different from the data collected during quiet sitting, which centred on 0. Examination of the histograms and data for the time taken to reach to the same side indicated that the median value was less for the young subjects than it was for the elderly subjects, and that the variation between subjects was greater for the elderly than the young subjects. The median value of the time taken for the young subjects was less than the 25th percentile for the elderly subjects, and the median value for the elderly subjects was greater than the 75th percentile for the young subjects. The median value for the elderly subjects was similar to the 95th percentile for the young subjects, demonstrating the extent of the difference between the distribution of the two groups.

Multiple regression was carried out to investigate the association between the symmetry and time variables and the independent variables (gender, age, age-group, height, body mass, lower-leg length, dominant hand). The R-squared and significance values are displayed in Table 15.3 - Table 15.5. The definition of significant association previously identified was used. There was a significant association between the time taken to reach to the same side and both age (R^2=0.178) and age-group (R^2=0.197). The association between the time taken and age confirmed the differences in the distribution of the time variables observed above. There was no significant association between the symmetry and time variables and any of the other independent variables.

For the significant associations found, "age" was the subject's age in years, and "age-group" was '1' for the young subjects and '2' for the elderly subjects. The regression equations (values for gradients and intercepts are provided in Table 15.5) indicate that the time taken by older subjects was longer than the time taken by younger subjects. The statistical differences between the time taken by the young and elderly subjects indicated that the two groups could not be combined for future analysis of the time variables. During comparison with subjects with hemiplegia the age of the hemiplegic subjects had to be considered.

independent variable	age	age group	gender	mass	height	lower leg length	dominant hand
R^2	0.020	0.016	0.002	0.014	0.007	0.002	0.061
t_m	0.380	0.443	0.768	0.468	0.619	0.803	0.113
t_c	0.000	0.000	0.000	0.000	0.009	0.000	0.000
gradient							
constant							

Table 15.3 R-squared and significance values for association between peak SI during reaching to the same side and independent variables.

independent variable	age	age group	gender	mass	height	lower leg length	dominant hand
R^2	0.049	0.043	0.075	0.000	0.015	0.014	0.003
t_m	0.167	0.201	0.087	0.981	0.444	0.470	0.744
t_c	0.800	0.844	0.407	0.671	0.353	0.348	0.578
gradient							
constant							

Table 15.4 R-squared and significance values for association between mean SI during sitting after reaching to the same side and independent variables.

independent variable	age	age group	gender	mass	height	lower leg length	dominant hand
R^2	0.178	0.197	0.026	0.001	0.089	0.060	0.002
t_m	0.007	0.004	0.317	0.835	0.062	0.128	0.805
t_c	0.000	0.000	0.000	0.000	0.001	0.001	0.000
gradient	0.027	1.364					
constant	6.212	5.426					

Table 15.5 R-squared and significance values for association between time to reach to the same side and independent variables.

15.3 Hemiplegic subjects

15.3.1 Baseline measurement (week 0)

The distribution of the symmetry and time variables from the hemiplegic subjects during the first test week (week 0) was compared with the results from the healthy subjects. The distribution of the peak SI during reaching to the same side, the mean SI after reaching, and the time taken to reach are illustrated in Figure 15.15, Figure 15.17 and Figure 15.19. The distributions of the same variables from the healthy subjects are provided in Figure 15.14, Figure 15.16 and Figure 15.18 to allow comparison. Figure 15.14 and Figure 15.16 show the distribution of the young and elderly healthy subjects combined, while Figure 15.18 displays the distribution of the time taken by the elderly healthy subjects as the young and elderly subjects were found to have significant differences in the distribution of this variable. The median and percentile values are listed in Table 15.6.

	Peak SI during reaching (SI)		Mean SI after reaching (SI)		Mean time to reach (s)	
	healthy	**hemiplegic**	**healthy**	**hemiplegic**	**elderly**	**hemiplegic**
median	0.845	0.633	0.035	-0.040	8.317	10.577
25th percentile	0.793	0.509	0.004	-0.114	7.105	8.790
75th percentile	0.894	0.716	0.073	0.066	8.955	12.482
interquartile range	0.101	0.207	0.069	0.180	1.850	3.692
5th percentile	0.688	0.284	-0.083	-0.275	5.607	7.454
95th percentile	0.938	0.823	0.142	0.242	11.468	14.647
90% range	0.250	0.539	0.226	0.517	5.861	7.193

Table 15.6 Medians and percentiles for reaching to the same side. Healthy and hemiplegic subjects.

The distribution of the peak SI during reaching to the same side was centred around a lower point on the SI and had a greater variation for the hemiplegic subjects than for the healthy subjects. The difference between the median values was considerable, with the median value for the hemiplegic subjects being less than the 5^{th} percentile for the healthy subjects. The 95^{th} percentile for the hemiplegic subjects was less than the median peak SI for the healthy subjects. The magnitude of the interquartile range and 90% range of the peak SI for the hemiplegic subjects was more than double those of the healthy subjects. The distribution of the mean SI during sitting after reaching for the healthy subjects was found to be centred around a point greater than 0 (0.035). The distribution of the mean SI during sitting after reaching for the hemiplegic subjects exhibited the opposite trend, with a median value of less than 0 (-0.040). The variation between the mean symmetry values after reaching was considerably greater for the hemiplegic subjects (90% range = 0.517) than for the healthy subjects (90% range = 0.226). There was a very large degree of variation between the time taken to reach to the same side by individual hemiplegic subjects (Figure 15.19). The median time taken to reach by the hemiplegic subjects (10.6s) was considerably longer than that taken by the elderly healthy subjects (8.3s).

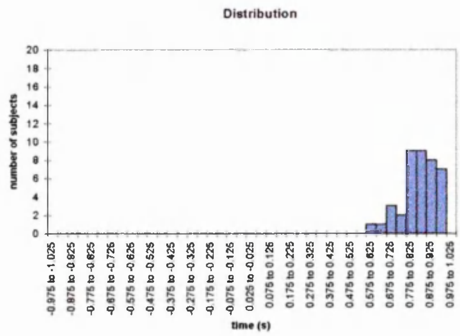


Figure 15.14 Distribution of peak symmetry index during reaching to the same side for healthy subjects (young and elderly combined).

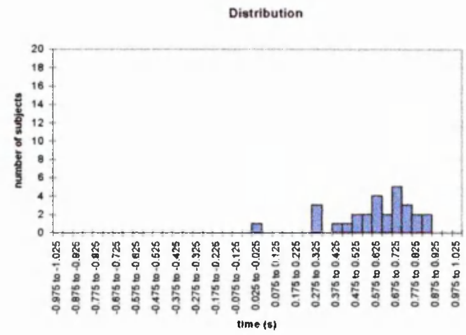


Figure 15.15 Distribution of peak symmetry index during reaching to the same side for hemiplegic subjects during week 0 (control and practice combined).

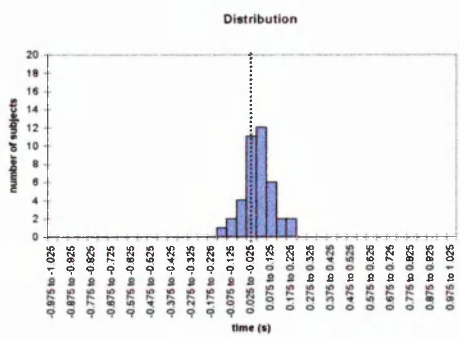


Figure 15.16 Distribution of mean symmetry index after reaching to the same side for healthy subjects (young and elderly combined).

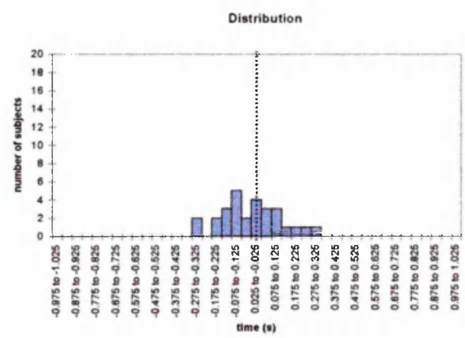


Figure 15.17 Distribution of mean symmetry index after reaching to the same side for hemiplegic subjects during week 0 (control and practice combined).

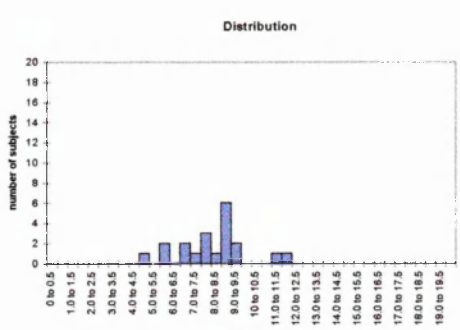


Figure 15.18 Distribution of time taken to reach to the same side for elderly healthy subjects.

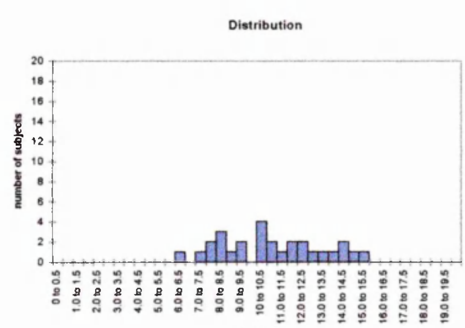


Figure 15.19 Distribution of time taken to reach to the same side for hemiplegic subjects during week 0 (control and practice combined).

15.3.2 Control and practice groups

The relatively low number of subjects in the control and practice groups, the decrease in numbers over the test weeks due to patient discharge, and the relatively large variation between individual subjects, prevented the use of statistical tests to compare the control group and practice group results. Subsequently, comparison between the control group and practice group results was carried out with the use of descriptive statistics. The median, percentiles and interquartile and 90% ranges of the symmetry and time data are shown in Table 15.7 - Table 15.12. The median and quartile ranges of the symmetry data are shown graphically in Figure 15.20, Figure 15.21 and Figure 15.22.

Control group versus healthy subjects

The median peak symmetry during reaching to the same side for the control group subjects was less than the median value for the healthy subjects throughout the test weeks. However the median peak symmetry value for the control group subjects increased over the test weeks, and was greater than the 5th percentile of the healthy subject data during test weeks 2-6, and was within the healthy subject interquartile range during week 5.

Comparison of the control group and the healthy subject median values for the mean SI during sitting after reaching demonstrated that, although the control group mean SI during sitting after reaching increased over the test weeks, it remained less than the healthy subject median value until week 6. The control group median values were less than the 25th percentile of the healthy subjects during test weeks 0-3, within the healthy subject interquartile range during test weeks 4 and 5 and greater than the 75th percentile of the healthy subjects during test week 6.

The time taken by the control group subjects to reach to the same side was longer than the time taken by the healthy elderly subjects on all test weeks, and the interquartile range was greater for the control group than the healthy elderly subjects on all test weeks.

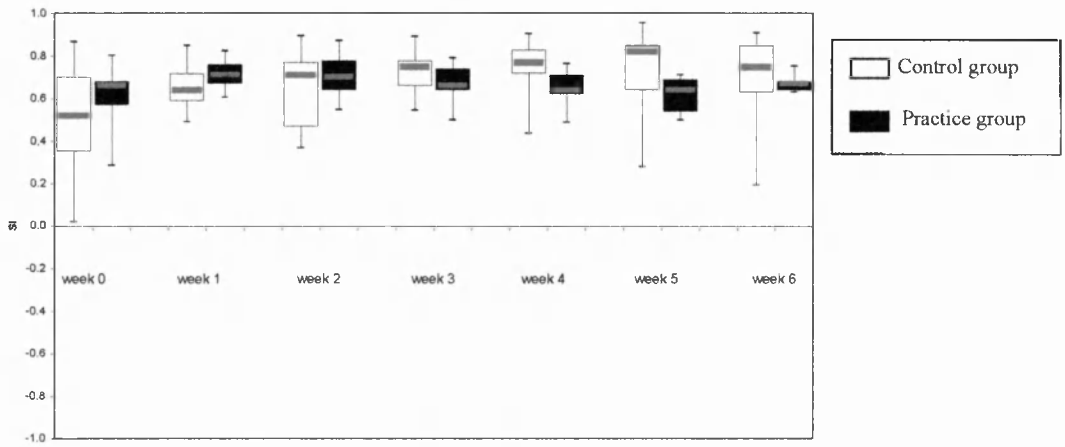


Figure 15.20 Medians, interquartile ranges and ranges of peak SI during reaching to the same side by control and practice group subjects.

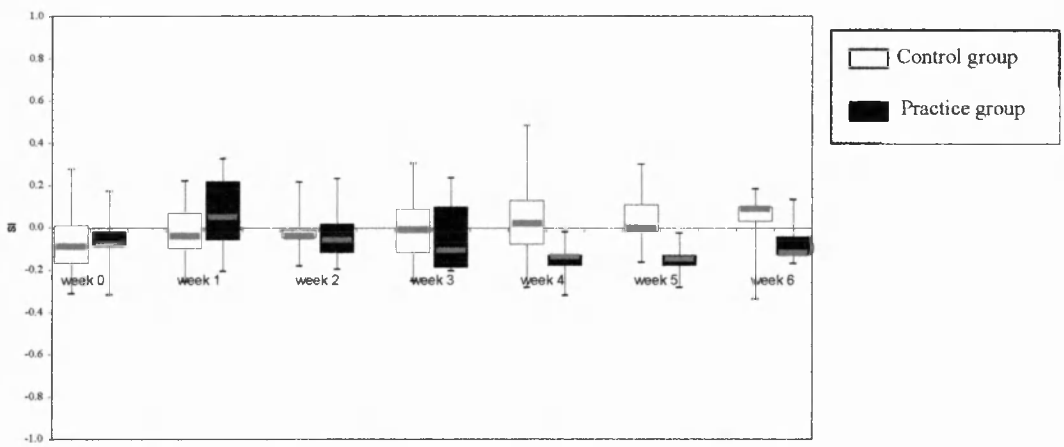


Figure 15.21 Medians, interquartile ranges and ranges of mean SI after reaching to the same side by control and practice group subjects.

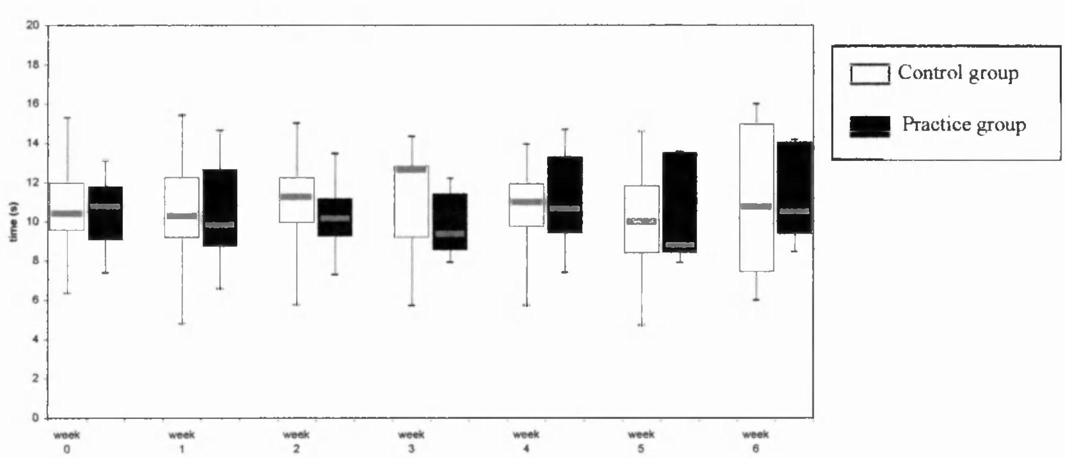


Figure 15.22 Medians, interquartile ranges and ranges of time taken to reach to the same side by control and practice group subjects.

	healthy	week 0	week 1	week 2	week 3	week 4	week 5	week 6
median	0.85	0.52	0.64	0.71	0.75	0.77	0.82	0.75
25th percentile	0.80	0.35	0.59	0.47	0.66	0.72	0.64	0.63
75th percentile	0.90	0.70	0.72	0.77	0.78	0.83	0.85	0.85
interquartile range	*0.10*	*0.35*	*0.13*	*0.30*	*0.12*	*0.11*	*0.21*	*0.22*
5th percentile	0.70	0.15	0.51	0.39	0.56	0.51	0.36	0.30
95th percentile	0.94	0.81	0.82	0.81	0.83	0.90	0.93	0.90
90% range	*0.24*	*0.66*	*0.31*	*0.42*	*0.27*	*0.38*	*0.57*	*0.60*

Table 15.7 Medians and percentiles for peak SI during reaching to the same side. Control group subjects (SI).

	healthy	week 0	week 1	week 2	week 3	week 4	week 5	week 6
median	0.85	0.66	0.71	0.70	0.66	0.64	0.64	0.67
25th percentile	0.80	0.57	0.67	0.64	0.64	0.62	0.54	0.64
75th percentile	0.90	0.68	0.76	0.78	0.74	0.71	0.69	0.68
interquartile range	*0.10*	*0.11*	*0.09*	*0.14*	*0.10*	*0.08*	*0.16*	*0.04*
5th percentile	0.70	0.36	0.62	0.56	0.53	0.52	0.51	0.63
95th percentile	0.94	0.76	0.82	0.85	0.78	0.75	0.71	0.74
90% range	*0.24*	*0.40*	*0.19*	*0.29*	*0.25*	*0.24*	*0.20*	*0.11*

Table 15.8 Medians and percentiles for peak SI during reaching to the same side. Practice group subjects (SI).

	healthy	week 0	week 1	week 2	week 3	week 4	week 5	week 6
median	0.03	-0.09	-0.04	-0.04	-0.01	0.02	0.00	0.09
25th percentile	0.00	-0.17	-0.10	-0.05	-0.12	-0.08	-0.02	0.03
75th percentile	0.07	0.01	0.07	-0.01	0.09	0.13	0.11	0.10
interquartile range	*0.07*	*0.18*	*0.17*	*0.04*	*0.21*	*0.21*	*0.13*	*0.07*
5th percentile	-0.08	-0.26	-0.23	-0.13	-0.22	-0.22	-0.13	-0.25
95th percentile	0.14	0.07	0.16	0.17	0.25	0.37	0.25	0.16
90% range	*0.23*	*0.33*	*0.39*	*0.31*	*0.48*	*0.59*	*0.38*	*0.41*

Table 15.9 Medians and percentiles for mean SI after reaching to the same side. Control group subjects (SI).

	healthy	week 0	week 1	week 2	week 3	week 4	week 5	week 6
median	0.03	-0.08	0.05	-0.06	-0.11	-0.14	-0.15	-0.12
25th percentile	0.00	-0.09	-0.06	-0.12	-0.19	-0.18	-0.18	-0.13
75th percentile	0.07	-0.02	0.22	0.02	0.10	-0.13	-0.13	-0.04
interquartile range	*0.07*	*0.06*	*0.28*	*0.14*	*0.29*	*0.04*	*0.05*	*0.09*
5th percentile	-0.08	-0.24	-0.17	-0.18	-0.20	-0.29	-0.26	-0.16
95th percentile	0.14	0.12	0.30	0.20	0.22	-0.04	-0.05	0.10
90% range	*0.23*	*0.37*	*0.47*	*0.39*	*0.42*	*0.25*	*0.21*	*0.26*

Table 15.10 Medians and percentiles for mean SI after reaching to the same side. Practice group subjects (SI).

	elderly	week 0	week 1	week 2	week 3	week 4	week 5	week 6
median	8.32	10.40	10.27	11.25	12.65	10.96	9.99	10.77
25th percentile	7.10	9.56	9.17	9.95	9.19	9.73	8.40	7.43
75th percentile	8.96	11.98	12.24	12.27	12.81	11.92	11.82	14.96
interquartile range	1.85	*2.42*	*3.07*	*2.32*	*3.62*	*2.19*	*3.42*	*7.53*
5th percentile	5.61	8.35	6.00	9.33	7.73	6.72	7.50	6.28
95th percentile	11.47	14.31	14.03	14.00	13.90	13.61	14.23	15.85
90% range	5.86	*5.96*	*8.03*	*4.67*	*6.16*	*6.89*	*6.73*	*9.57*

Table 15.11 Medians and percentiles for time taken to reach to the same side. Control group subjects (s).

	elderly	week 0	week 1	week 2	week 3	week 4	week 5	week 6
median	8.32	10.75	9.81	10.14	9.33	10.61	8.77	10.49
25th percentile	7.10	9.06	8.74	9.25	8.53	9.39	8.41	9.36
75th percentile	8.96	11.79	12.67	11.17	11.40	13.29	13.50	14.05
interquartile range	1.85	*2.73*	*3.93*	*1.91*	*2.87*	*3.90*	*5.09*	*4.69*
5th percentile	5.61	7.67	6.99	7.47	8.04	7.79	7.99	8.61
95th percentile	11.47	12.99	14.29	12.97	12.12	14.38	13.52	14.15
90% range	5.86	*5.33*	*7.29*	*5.49*	*4.07*	*6.59*	*5.53*	*5.53*

Table 15.12 Medians and percentiles for time taken to reach to the same side. Practice group subjects (s).

Practice group versus healthy subjects

As for the control group, the median peak symmetry value for the practice group subjects was lower than the median value from the healthy subjects throughout the test weeks. In contrast to the control group subjects, the median peak symmetry value of the practice group cannot be observed to increase over the test weeks, and remained less than the 5^{th} percentile value of the healthy subjects during test weeks 0, 3, 4, 5 and 6.

The median value of the mean SI during sitting after reaching for the practice group was less than the healthy subject median value on all test weeks. The median SI during sitting after reaching for the practice group subjects was above the 5^{th} percentile of the healthy subjects during test weeks 0-2, but below this value during test week 3-6.

As for the control group, the time taken by the practice group subjects to reach to the same side was longer than the time taken by the healthy elderly subjects on all test weeks. The interquartile range for the time taken was greater for the practice group than the healthy elderly subjects on all test weeks.

Control group versus practice group

The median peak SI increased from week 0 to week 5 for the control group. In contrast, there was no increase in the median peak SI over the test weeks for the practice group. Relative to the healthy subject data, the median value of the peak SI for the control group was greater than the 5^{th} percentile during test weeks 2-6, while the median value of the peak SI for the practice group was less than the 5^{th} percentile during test weeks 3-6. Figure 15.21 indicated that the mean SI during sitting after reaching to the same side for the control group subjects tended to become greater over the test weeks, while that of the practice group subjects tended to become less over the test weeks. There was little observable difference between the time taken to reach to the same side by the control and practice group subjects throughout the test weeks. There were no remarkable trends or patterns in the time data.

15.3.3 Effect of discharge on group results

The numbers of subjects in both the control and practice groups decreased over the test weeks as subjects were discharged from the trial. It was therefore possible that observing the results for the groups of subjects had masked trends in the outcome variables of individual subjects. The results of the subjects who had measurements taken on all 7 test weeks, and the results of subjects who were discharged home prior to week 6, potentially provided information pertaining to trends in the data over time. Table 15.13 - Table 15.18 display the medians and interquartile ranges for the outcome variables for control and practice group subjects who were not discharged during, who were discharged home and who were discharged for other reasons during the test period. Figure 15.23, Figure 15.24 and Figure 15.25 illustrate the median, interquartile range and range of the outcome measures for the control and practice group subjects who were not discharged during the test period.

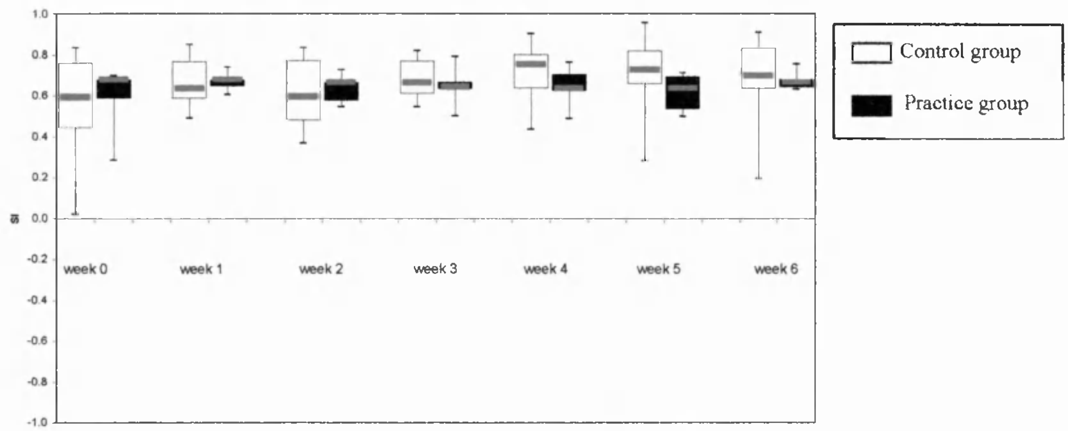


Figure 15.23 Median, interquartile range and range of peak symmetry during reaching to the same side for hemiplegic subjects completing 7 test weeks.

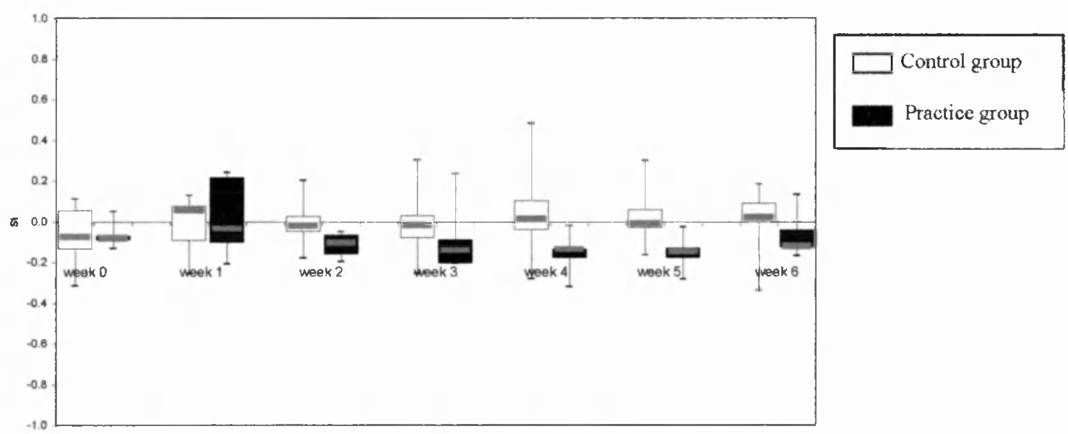


Figure 15.24 Median, interquartile range and range of mean symmetry after reaching to the same side for hemiplegic subjects completing 7 test weeks.

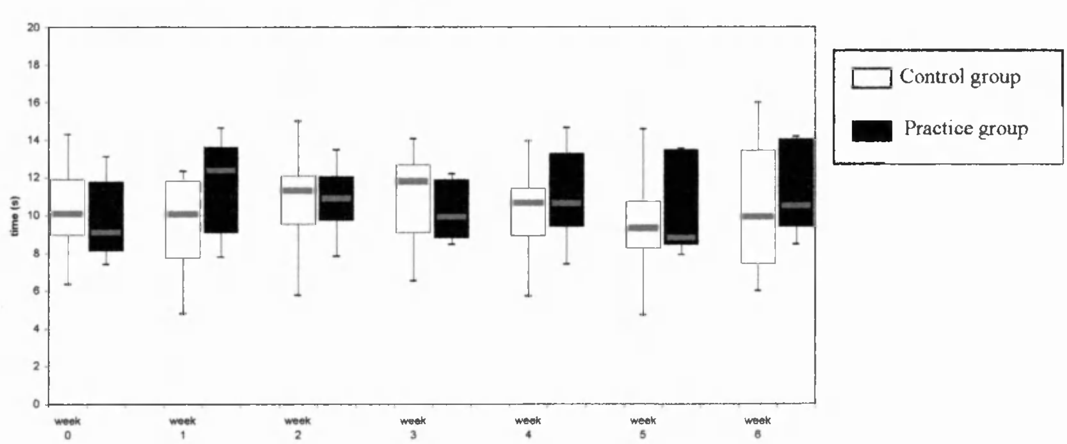


Figure 15.25 Median, interquartile range and range of time taken to reach to the same side for hemiplegic subjects completing 7 test weeks.

Group	Discharge status	week 0	week 1	week 2	week 3	week 4	week 5	week 6
control	not discharged	0.594	0.638	0.596	0.665	0.755	0.729	0.699
	discharged home	0.670	0.652	0.721	0.799	0.785	0.807	
	discharged other	0.428	0.723	0.895	0.875			
practice	not discharged	0.678	0.679	0.665	0.646	0.636	0.637	0.667
	discharged home	0.685	0.771	0.790	0.764			
	discharged other	0.573	0.824	0.872				

Table 15.13 Median values of peak symmetry during reaching to the same side for control and practice groups according to discharge status (SI).

Group	Discharge status	week 0	week 1	week 2	week 3	week 4	week 5	week 6
control	not discharged	0.316	0.180	0.292	0.159	0.165	0.162	0.199
	discharged home	0.083	0.095	0.066	0.133	0.110	0.095	
	discharged other	0.291	0.082	0.000	0.000			
practice	not discharged	0.094	0.032	0.090	0.034	0.082	0.159	0.039
	discharged home	0.118	0.028	0.011	0.000			
	discharged other	0.091	0.000	0.000				

Table 15.14 Interquartile range values for peak symmetry during reaching to the same side for control and practice groups according to discharge status (SI).

Group	Discharge status	week 0	week 1	week 2	week 3	week 4	week 5	week 6
control	not discharged	-0.074	0.056	-0.020	-0.016	0.014	-0.009	0.022
	discharged home	0.022	-0.067	-0.026	-0.085	0.071	0.145	
	discharged other	0.049	0.089	0.215	-0.056			
practice	not discharged	-0.080	-0.034	-0.104	-0.142	-0.138	-0.149	-0.120
	discharged home	0.042	0.140	0.062	0.158			
	discharged other	-0.171	0.125	0.232				

Table 15.15 Median values of mean symmetry after reaching to the same side for control and practice groups according to discharge status (SI).

Group	Discharge status	week 0	week 1	week 2	week 3	week 4	week 5	week 6
control	not discharged	0.191	0.170	0.074	0.110	0.144	0.088	0.096
	discharged home	0.174	0.064	0.124	0.176	0.102	0.039	
	discharged other	0.211	0.132	0.000	0.000			
practice	not discharged	0.021	0.321	0.096	0.117	0.044	0.048	0.086
	discharged home	0.129	0.186	0.088	0.000			
	discharged other	0.147	0.000	0.000				

Table 15.16 Interquartile range values for mean symmetry after reaching to the same side for control and practice groups according to discharge status (SI).

Group	Discharge status	week 0	week 1	week 2	week 3	week 4	week 5	week 6
control	not discharged	10.087	10.057	11.297	11.793	10.647	9.300	9.910
	discharged home	12.813	9.230	10.280	9.320	9.473	7.627	
	discharged other	10.400	11.377	8.987	5.693			
practice	not discharged	9.060	12.347	10.867	9.887	10.613	8.767	10.493
	discharged home	11.477	7.847	8.843	7.907			
	discharged other	10.777	10.507	9.880				

Table 15.17 Median values of time taken to reach to the same side for control and practice groups according to discharge status (s).

Group	Discharge status	week 0	week 1	week 2	week 3	week 4	week 5	week 6
control	not discharged	2.973	4.108	2.573	3.613	2.565	2.478	6.042
	discharged home	5.867	2.118	2.382	3.940	0.807	1.408	
	discharged other	2.393	4.037	0.000	0.000			
practice	not discharged	3.693	4.573	2.333	3.120	3.900	5.093	4.687
	discharged home	1.350	1.273	1.563	0.000			
	discharged other	0.023	0.000	0.000				

Table 15.18 Interquartile range values for time taken to reach to the same side for control and practice groups according to discharge status (s).

The median peak SI during reaching to the same side for the control group subjects who were not discharged was slightly greater during test weeks 4, 5 and 6 than during test week 0-3. For the whole control group results the median peak SI was observed to increase throughout the test period. The median peak SI for the control group subjects who were discharged home or discharged for other reasons had an upward trend over the test weeks. Thus the increasing trend in the whole group may have been influenced by the results from the control group subjects who were discharged, although a slight increase was present in the control group subjects who were not discharged. There was little difference in the pattern of results for the whole practice group and the practice group subjects who were not discharged during the test period. There was little change in the median value of the peak SI for the whole practice group or for the practice group subjects who were not discharged during the test period.

The results for the control group subjects who were not discharged indicated that there was no trend or pattern in the mean SI during sitting after reaching. This contrasted with the whole group results that indicated that the mean SI increased slightly over the test period. For the control group subjects who were discharged no remarkable trends or patterns were observed in the data pertaining to the mean SI during sitting after reaching. This indicates that there were no trends in the mean SI during sitting after reaching for the control group subjects. However, a tendency for the mean SI during sitting after reaching for the practice group subjects to decrease over the test weeks was observed for the practice group subjects who were not discharged. This accords with the whole group pattern that was observed.

As in the whole group results, there were no observable trends in the time taken to reach to the same side for either the control or practice group subjects who were not discharged. However, in both the control and practice group subjects who were discharged home, the time taken was observed to decrease over the test weeks.

Thus, although the whole group results suggested that the peak SI for the control group increased over the test weeks, examination of the data according to discharge status indicated that there was no trend in the data of subjects who were not discharged. There was therefore insufficient evidence to support the existence of trends in the peak SI data for the control or practice group subjects over the test weeks. There were no trends in the data for the mean SI during sitting after reaching for the control group subjects; the mean SI during sitting after reaching for the practice group decreased over the test weeks. There were no trends in the time taken over the test weeks to reach to the same side for the hemiplegic subjects who were not discharged; however the time taken by subjects who were discharged home during the test period was observed to decrease over the test weeks.

15.3.4 Classification of ability

Using the definition of 'normal' values previously determined the proportion of hemiplegic subjects with symmetry and time data within the normal range was determined. The normal range was equal to the 90% range from the healthy subject data, with the young and elderly subjects combined, for the peak symmetry variable and the mean symmetry after reaching variable, but was defined as equal to the 90% range from the elderly healthy subjects only for the time variable (see section 15.2). The proportion of control and practice group subjects with the outcome variables falling within the normal range are illustrated in Table 15.19 - Table 15.21, and in Figure 15.26 - Figure 15.31.

	Control			Practice			
	unable	abnormal	normal	unable	abnormal	normal	*Chi^2*
Week 0	0%	58%	42%	0%	78%	22%	*0.305*
Week 1	0%	61%	39%	0%	50%	50%	*0.597*
Week 2	0%	41%	59%	0%	50%	50%	*0.678*
Week 3	0%	43%	57%	0%	67%	33%	*0.400*
Week 4	0%	27%	73%	0%	60%	40%	*0.176*
Week 5	0%	43%	57%	0%	60%	40%	*0.510*
Week 6	0%	40%	60%	0%	80%	20%	*0.143*

Table 15.19 Proportion of control and practice group subjects achieving normal peak symmetry during reaching to the same side, and the Chi^2 statistic for the difference between the ability of the control and practice group subjects.

	Control			Practice			
	unable	abnormal	normal	unable	abnormal	normal	*Chi^2*
Week 0	0%	53%	47%	0%	56%	44%	*0.885*
Week 1	0%	33%	67%	0%	62%	38%	*0.165*
Week 2	0%	24%	76%	0%	63%	38%	*0.058*
Week 3	0%	36%	64%	0%	100%	0%	*0.016*
Week 4	0%	33%	67%	0%	80%	20%	*0.069*
Week 5	0%	50%	50%	0%	80%	20%	*0.243*
Week 6	0%	20%	80%	0%	60%	40%	*0.121*

Table 15.20 Proportion of control and practice group subjects achieving normal mean symmetry after reaching to the same side, and the Chi^2 statistic for the difference between the ability of the control and practice group subjects.

	Control			Practice			
	unable	abnormal	normal	unable	abnormal	normal	*Chi^2*
Week 0	0%	42%	58%	0%	33%	67%	*0.657*
Week 1	0%	44%	56%	0%	38%	62%	*0.741*
Week 2	0%	35%	65%	0%	25%	75%	*0.607*
Week 3	0%	40%	60%	0%	33%	67%	*0.788*
Week 4	0%	27%	73%	0%	40%	60%	*0.573*
Week 5	0%	21%	79%	0%	40%	60%	*0.418*
Week 6	0%	40%	60%	0%	40%	60%	*1.000*

Table 15.21 Proportion of control and practice group subjects achieving normal time to reach to the same side, and the Chi^2 statistic for the difference between the ability of the control and practice group subjects.

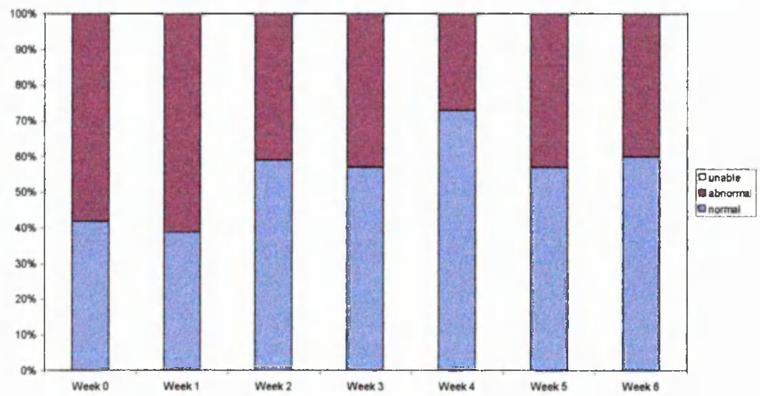


Figure 15.26 Proportion of control group subjects achieving normal peak symmetry index during reaching to the same side on different test weeks.

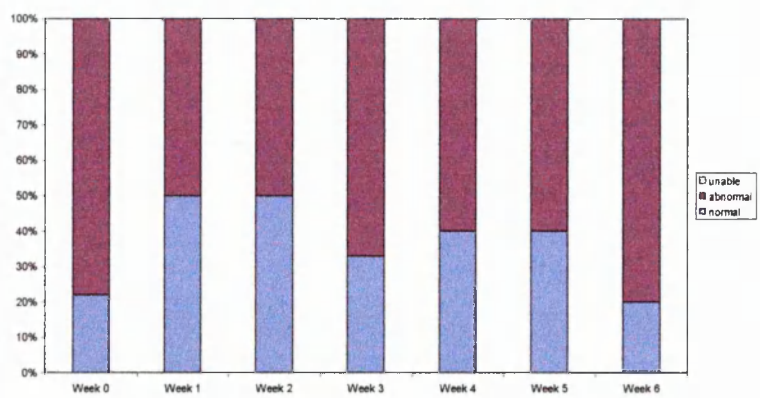


Figure 15.27 Proportion of practice group subjects achieving normal peak symmetry index during reaching to the same side on different test weeks.

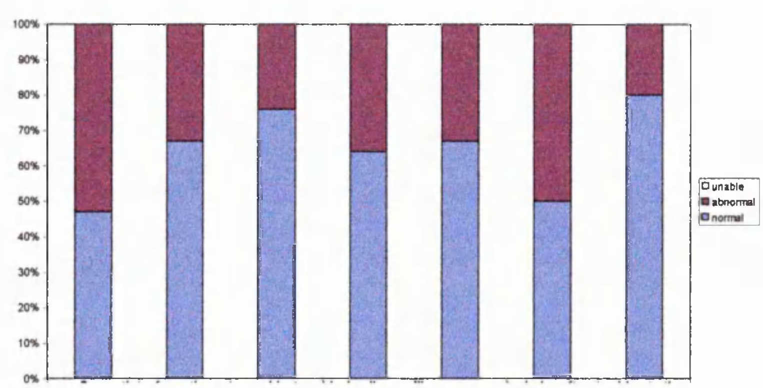


Figure 15.28 Proportion of control group subjects achieving normal mean symmetry index after reaching to the same side on different test weeks.

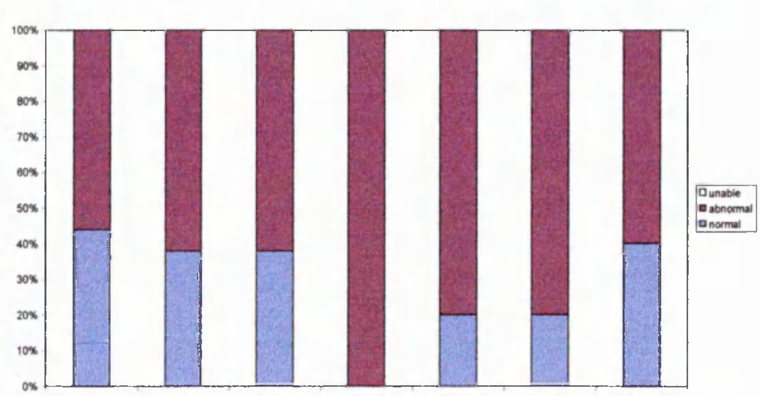


Figure 15.29 Proportion of practice group subjects achieving normal mean symmetry index after reaching to the same side on different test weeks.

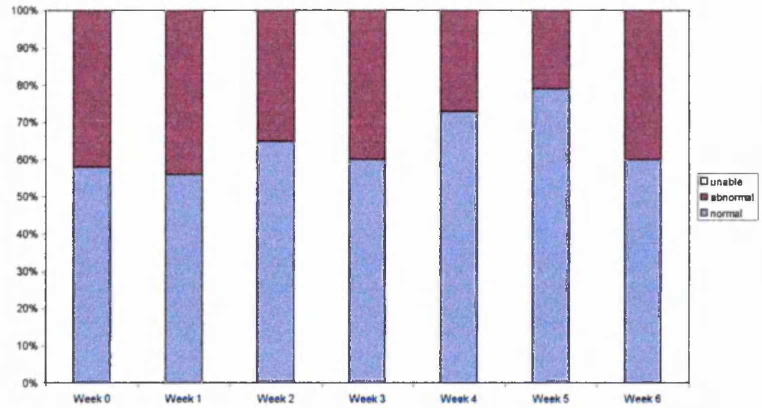


Figure 15.30 Proportion of control group subjects achieving normal time to reach to the same side on different test weeks.

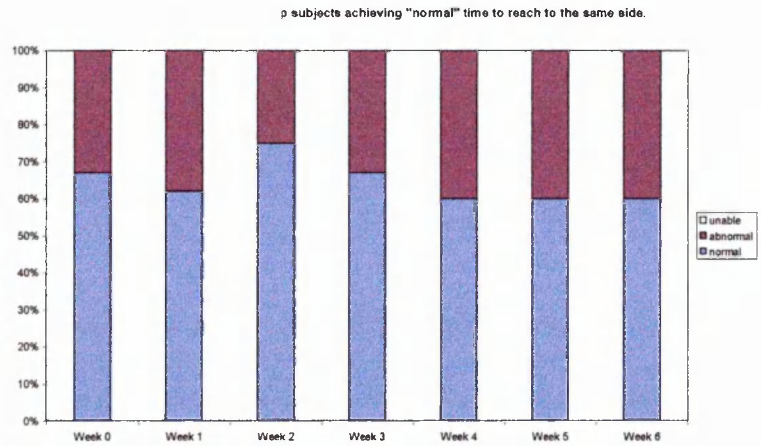


Figure 15.31 Proportion of practice group subjects achieving normal time to reach to the same side on different test weeks.

A higher proportion of control group subjects (42%) than practice group subjects (22%) demonstrated a peak SI during reaching to the same side which was in the normal range at the time of the initial measurement. This pattern continued throughout the test weeks, with the control group having a higher proportion of subjects with normal peak SI than the practice group during each test week. Although no trends could be observed in the proportion of control or practice group subjects achieving normal peak symmetry indices during reaching, the proportion of control group subjects achieving normal peak symmetry at test week 6 was considerably higher than the proportion of practice group subjects (control 60%, practice 20%). Despite these differences that can be observed between the control and practice group subjects, the Chi-squared test demonstrated that none of the observable differences were statistically significant (Table 15.19).

The proportion of control and practice group subjects with normal mean symmetry indices during sitting after reaching was similar on test week 0 (control 47%, practice 44%). However, on all subsequent test weeks the proportion achieving normal weight distribution was less for the practice group than for the control group. During test week 2 this difference neared statistical significance (Chi^2 = 0.058), and during test week 3 this difference reached statistical significance (Chi^2= 0.016). There were no remarkable trends in the pattern of the mean SI during sitting after reaching for either the control or practice group subjects.

There were no observable differences between the ability of the control or practice group subjects to achieve normal time to reach to the same side during any of the test weeks. The proportion of subjects achieving normal time to reach on any test week was between 56% and 79% for the control group, and between 60% and 75% for the practice group. There was little change in the proportion of subjects achieving normal time to reach to the same side throughout the test period. This was confirmed by the Chi-squared values.

The number of control and practice group subjects whose ability to reach to the same side changed, relative to the "normal", between their first and last test of reaching to the same side is shown in Table 15.22 - Table 15.24. These results demonstrate that the ability of over half of the control (0%+26%+32% = 58%) and practice (0%+44%+11% = 55%) group subjects to achieve normal peak symmetry during reaching to the same side did not change. Of the subjects whose ability did change, the ability of approximately ¾ improved, and approximately ¼ deteriorated. This pattern of change was very similar for the ability of the control group subjects to achieve normal mean symmetry of weight distribution after reaching to the same side. However, the pattern of change in the ability of the practice group subjects to achieve normal mean symmetry of weight distribution after reaching to the same side was different, with the ability of 89% (0%+56%+33%) of the subjects not changing between their first and last measurement. The changes in the ability of the control and practice group subjects to achieve normal time to reach to the same side were similar, with approximately 70% of the subjects having no change in their ability, approximately 20% improving, and approximately 10% deteriorating.

Ability at final measurement

Initial ability	Control			Practice		
	unable	abnormal	normal	unable	abnormal	normal
Unable	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
Abnormal	0 (0%)	5 (26%)	6 (32%)	0 (0%)	4 (44%)	3 (33%)
Normal	0 (0%)	2 (11%)	6 (32%)	0 (0%)	1 (11%)	1 (11%)

Table 15.22 Number (and percentage) of control and practice group subjects with ability to achieve normal peak symmetry index during reaching to the same side changing between the initial and final measurement.

Ability at final measurement

Initial ability	Control			Practice		
	unable	abnormal	normal	Unable	abnormal	normal
Unable	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
Abnormal	0 (0%)	4 (21%)	6 (32%)	0 (0%)	5 (56%)	1 (11%)
Normal	0 (0%)	2 (11%)	7 (37%)	0 (0%)	0 (0%)	3 (33%)

Table 15.23 Number (and percentage) of control and practice group subjects with ability to achieve normal mean symmetry of weight distribution after reaching to the same side changing between the initial and final measurement.

Ability at final measurement

Initial ability	Control			Practice		
	unable	abnormal	normal	Unable	abnormal	normal
Unable	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
Abnormal	0 (0%)	5 (26%)	3 (16%)	0 (0%)	1 (11%)	2 (22%)
Normal	0 (0%)	9 (11%)	2 (47%)	0 (0%)	1 (11%)	5 (56%)

Table 15.24 Number (and percentage) of control and practice group subjects with ability to achieve normal time during reaching to the same side changing between the initial and final measurement.

16. Results: Reaching across to the opposite side

16.1 Raw data and analysis

The symmetry index was determined for each test of reaching across to the opposite side. Examples of the SI during reaching across to the opposite side for a young, elderly, and hemiplegic subject are provided in Figure 16.1, Figure 16.2 and Figure 16.3. In addition to displaying the SI, these graphs display the point where the SI reaches its' peak and the points where the movement was identified to start and stop.

As in the analysis of reaching to the same side, there was an absence of measures of symmetry of weight distribution during reaching across to the opposite side reported in the literature. It could not be assumed that the pattern of symmetry of weight distribution during reaching to the same side and reaching across to the opposite side would be similar. It was therefore initially necessary to define the start and end of the movement; to ensure the movement of reaching across to the opposite side produced a distinct and reproducible pattern; and hence to identify appropriate outcome measures.

16.1.1 Identification of start and end of movement

The start and end of the movement were determined using the same methodology used to determine the start and end of the movement of the reaching to the same side (see section 15.1.1).

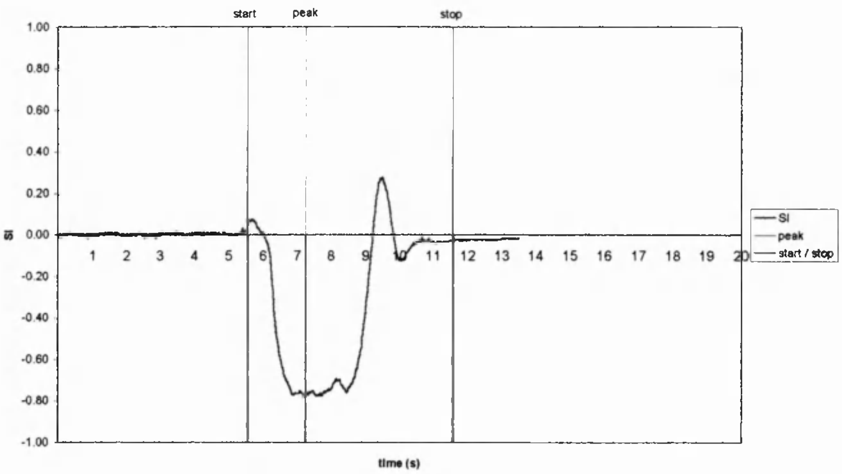


Figure 16.1 Symmetry index during reaching across to the opposite side. Young healthy subject.

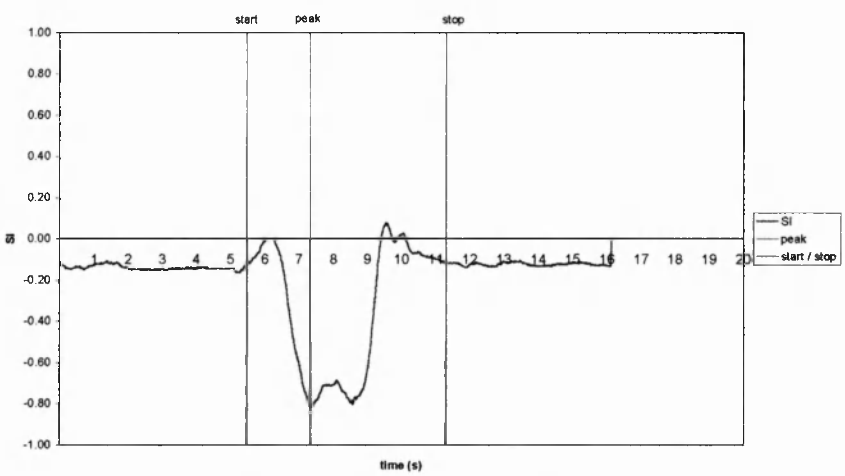


Figure 16.2 Symmetry index during reaching across to the opposite side. Elderly healthy subject.

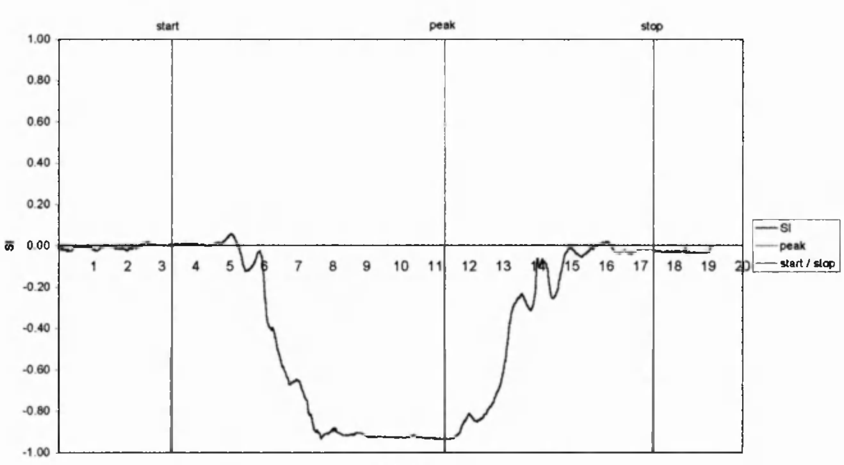


Figure 16.3 Symmetry index during reaching across to the opposite (affected) side. Hemiplegic subject.

16.1.2 Pattern of movement

In order to check the consistency of the pattern of movement the same process as was used in the exploration of the pattern of movement during reaching to the same side was adopted (section 15.1.2). This process involved determining the start and end of movement for each healthy subject, and converting the time scale to a scale containing 100 data points. The mean and standard deviation of the pattern of movement for the healthy subjects were than derived. The graph of the mean and two standard deviations either side for the young healthy subjects is shown in Figure 16.4. The pattern of movement for the elderly subjects was similar. This process demonstrated that there was a consistent pattern of movement, with a small degree of variation between healthy subjects. The pattern of the SI during reaching across to the opposite side was observed to be similar to, although the mirror image of, the pattern of the SI during reaching to the same side. The pattern that was observed started with a SI close to zero, which then increased to a peak (negative SI), before returning and remaining at a point close to zero.

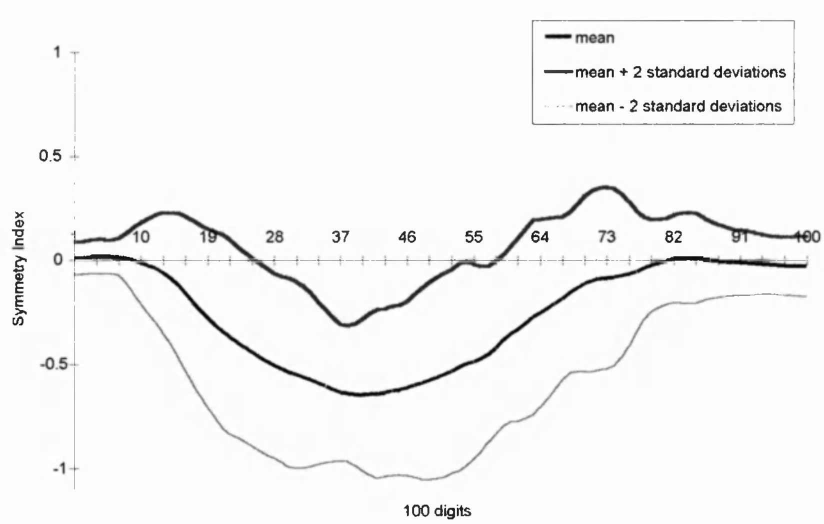


Figure 16.4 Mean pattern of symmetry index during reaching across to the opposite side. Young healthy subjects.

16.1.3 Selection of outcome variables

As was described for reaching to the same side, the analysis of reaching across to the opposite side was fundamentally different from the analysis of the "symmetrical" tasks of sitting, standing, rising to stand and sitting down. The goal of reaching across to the opposite side was to achieve a maximal *asymmetry*, followed by a return to a quiet sitting posture. The similarity between the goals and the patterns of movement during reaching to the same side and reaching across to the opposite side supported the use of similar outcome variables for both tasks. Thus the peak SI (maximum negative SI) was selected as an outcome variable and assumed to be a direct measure of the magnitude of weight transference during reaching across to the opposite side. The mean SI during sitting after reaching was also assumed to be an appropriate outcome variable for the analysis of reaching across to the opposite side, and was defined as the mean SI over the 1 second following the end of movement (as for reaching to the same side, section 15.1.3). The time taken to execute the movement was also defined as an outcome variable.

Hence the outcome variables selected for the analysis of reaching across to the opposite side were the peak (maximum negative) SI, the mean SI during sitting after reaching, and the time taken to reach across to the opposite side. These variables were similar to those selected for the analysis of reaching to the same side and, subsequently, allowed comparison between the two tasks.

16.2 Healthy subjects

The percentage close agreement for each of the three outcome variable of the 3 trials of reaching across to the opposite side for the young and elderly subjects are provided in Table 16.1.

		PCA (80%)	PCA (90%)	PCA (95%)	PCA (100%)
PEAK SI	*Young*	0.08	0.12	0.18	0.25
	Elderly	0.08	0.12	0.12	0.15
MEAN SI AFTER REACHING	*Young*	0.05	0.06	0.08	0.12
	Elderly	0.08	0.09	0.10	0.35
TIME (S)	*Young*	3.5	3.75	4.25	5.75
	Elderly	2.75	3.25	4.0	5.0

Table 16.1 PCA for reported variables from 3 repeated trials of reaching across to the opposite side; young and elderly healthy subjects.

The variation between the 3 repeated measures of the peak SI during reaching to the opposite side was low, although not as low as the variation between repeated measures of reaching to the same side. 90% of the differences between the repeated measures were less than 0.12 for the young and elderly subjects for reaching across to the opposite side (for reaching to the same side the equivalent values were 0.07 and 0.10 for the young and elderly subjects respectively). The variation between the 3 repeated measures of the mean SI during sitting after reaching to the opposite side was also low, with 90% of the differences between the repeated measures being less than 0.06 and 0.09 for the young and elderly subjects respectively. An exception to the low variation was observed in the 100% PCA for the elderly subjects (0.35). The difference between this value and the 95% PCA (0.10) indicates that the 100% PCA may be a statistical outlier. With the exception of this value the variation between the repeated measures of the mean SI after reaching was similar during reaching to the same side and reaching to the opposite side. The variation between the repeated measures of the time taken to reach to the opposite side (90% within 3.75s and 3.25s for young and elderly respectively) was also similar to the variation between the time taken to reach to the same side (90% within 3.75s and 4.5s for young and elderly respectively).

The variation between the 3 repeated measures of reaching to the opposite side for the peak SI, the mean SI after movement and the time taken are displayed graphically in Figure 16.5, Figure 16.6 and Figure 16.7. These graphs display the data from the elderly healthy subjects; the pattern of results from the young healthy subjects was similar. It can be observed that the variation between the repeated measures and between the subjects was similar to that found for healthy subjects reaching to the same side. The mean value for the 3 repeated measures of the peak SI fell within a range of 0.27 for 90% of the young healthy subjects, and within a range of 0.23 for the elderly healthy subjects. The mean value for the 3 repeated measures of the mean SI during sitting after reaching fell within a range of 0.11 for 90% of the young healthy subjects, and within a range of 0.28 for 90% of the elderly healthy subjects. Comparing these values with the maximum difference between the repeated measures demonstrated by 90% of the healthy subjects (0.12 and 0.12 for the peak SI and 0.06 and 0.09 for the mean SI during sitting after reaching, for the young and elderly subjects respectively) indicates that the variation between the subjects was greater than the variation between repeated measures.

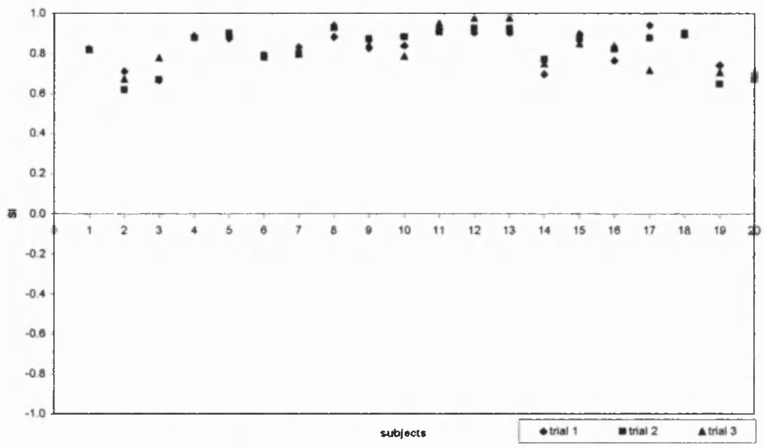


Figure 16.5 Peak symmetry index from 3 trials of reaching across to the opposite side. Elderly healthy subjects.

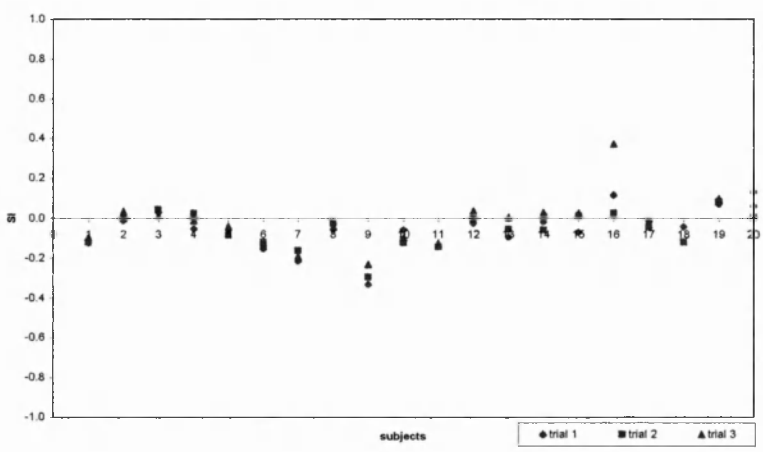


Figure 16.6 Mean symmetry index during sitting after reaching across to the opposite side. Elderly healthy subjects.

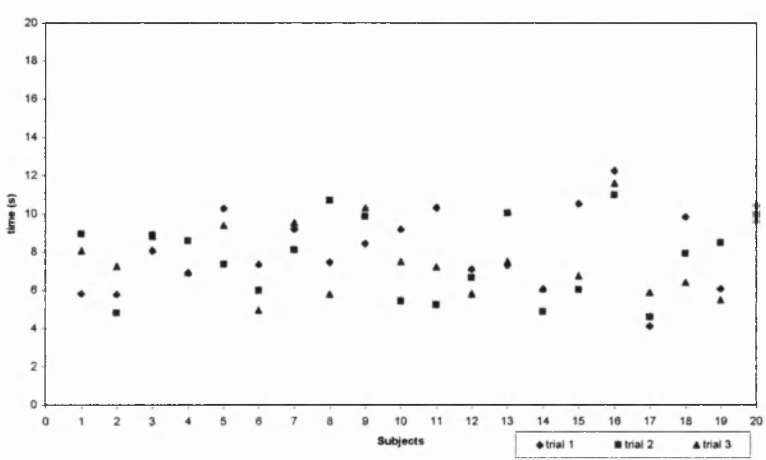


Figure 16.7 Mean time taken during 3 trials of reaching across to the opposite side. Elderly healthy subjects.

The variation between repeated measures and the variation between the subjects for the time taken to reach was similar, with 90% of the mean times taken to reach being within a range of 2.7s and 90% of the differences between repeated measures being less than 3.75s for the young subjects. For the elderly subjects these values were 4.5s and 3.25s respectively.

The mean of the outcome variables for the 3 tests of reaching across to the opposite side was determined and reported in all subsequent analysis.

The distribution of the mean variables for reaching across to the opposite side for the young and elderly healthy subjects are displayed in Figure 16.8 to Figure 16.13. The median values and the 5th, 25th, 75th and 95th percentiles for the young and elderly subjects are shown in Table 16.2. The distribution of the peak SI during reaching across to the opposite side occurred around a point very close to the lower limits of the SI. The distribution of the peak SI for reaching across to the opposite side for young healthy subjects was observed to be normal, while that for the elderly healthy subjects had a shift toward the right side of the curve. The median values, interquartile and 90% range for the peak of reaching across to the opposite side were similar for the young and elderly subjects, and were similar to those for reaching to the same side.

	Peak SI during reaching (SI)		Mean SI after reaching (SI)		Mean time to reach (s)	
	young	elderly	young	elderly	young	elderly
median	-0.835	-0.791	-0.027	-0.012	7.180	7.373
25th percentile	-0.877	-0.843	-0.045	-0.088	6.170	6.553
75th percentile	-0.791	-0.755	0.002	0.030	8.247	8.003
interquartile range	0.086	0.088	0.046	0.118	2.077	1.450
5th percentile	-0.929	-0.893	-0.079	-0.142	5.858	5.726
95th percentile	-0.709	-0.642	0.070	0.120	9.106	10.099
90% range	0.220	0.251	0.149	0.262	3.248	4.373

Table 16.2 Medians and percentiles for reaching across to the opposite side. Young and elderly healthy subjects.

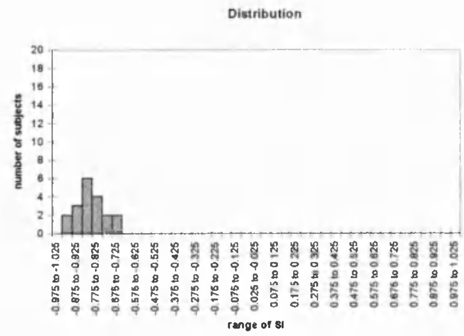


Figure 16.8 Distribution of peak symmetry index during reaching across to the opposite side for young healthy subjects.

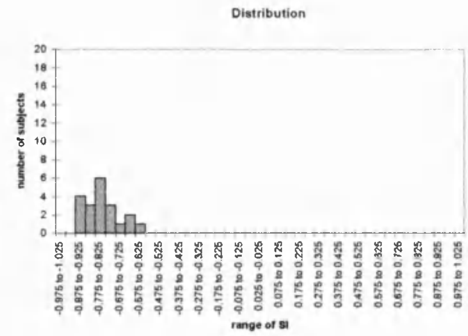


Figure 16.9 Distribution of peak symmetry index during reaching across to the opposite side for elderly healthy subjects.

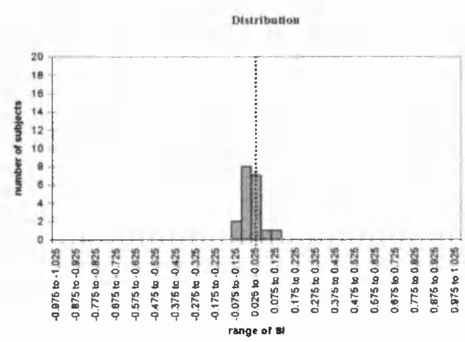


Figure 16.10 Distribution of mean symmetry index after reaching across to the same side for young healthy subjects.

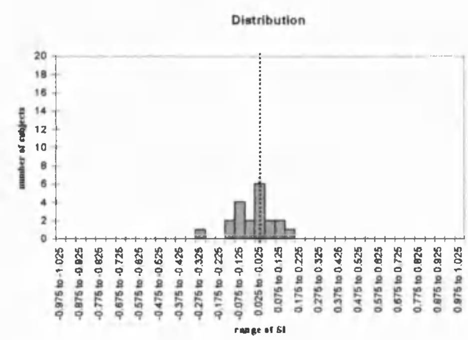


Figure 16.11 Distribution of mean symmetry index after reaching across to the same side for elderly healthy subjects.

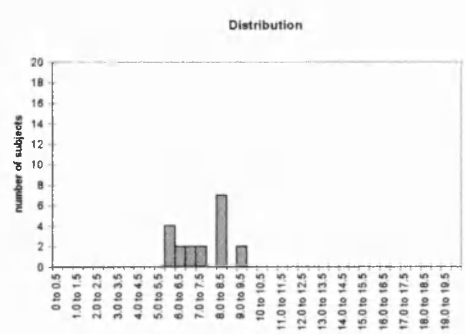


Figure 16.12 Distribution of time taken to reach across to the opposite side for young healthy subjects.

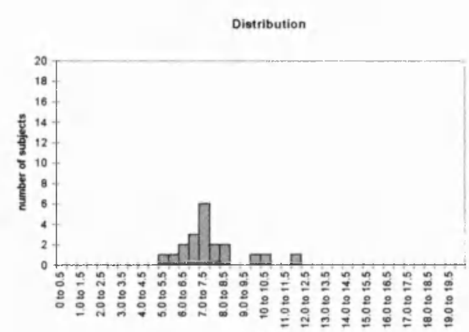


Figure 16.13 Distribution of time taken to reach across to the opposite side for elderly healthy subjects.

The distribution of the mean SI during the period of sitting after reaching across to the opposite side indicated that the distribution was centred on a point lower than 0. This reflects the same pattern as the mean SI during the period of sitting after reaching to the same side where the median values were greater than 0. However, in the case of the data for reaching across to the opposite side the interquartile range included zero within its range: this did not occur with the reaching to the same side data. The interquartile range and 90% range for the mean SI after reaching across to the opposite side were less for the young subjects than for the elderly subjects: the difference was similar to that between the young and elderly subjects for this variable in the measurement of reaching to the same side. Comparing the distribution of the time taken during reaching across to the opposite side for the young and elderly subjects was confounded by the non-normal distribution of this data. However, observation of the median and percentile values suggests that the time taken by the young and elderly subjects was similar. This was not the case in the comparison of the time taken during reaching to the same side, where the elderly subjects took longer to perform the task.

Multiple regression was carried out to investigate the association between the symmetry and time variables and the independent variable (gender, age, age-group, height, body mass, lower-leg length, dominant hand). The R-squared and significance values are displayed in Table 16.3 - Table 16.5. The definition of significant association previously identified was used. There was a significant association between the time taken to reach to the opposite side and gender (R^2=0.126). There was no significant association between the symmetry and time variables and any of the other independent variables.

For the significant association between gender and the time taken to reach across to the opposite side, "gender" was rated as '1' for males and '2' for females. The regression equation (values for gradients and intercepts provided in Table 16.5) implies that females took significantly longer to reach across to the opposite side than males.

independent variable	age	age group	gender	mass	height	lower leg length	dominant hand
R^2	0.082	0.070	0.015	0.062	0.000	0.039	0.001
t_m	0.078	0.104	0.459	0.124	0.964	0.229	0.872
t_c	0.000	0.000	0.000	0.000	0.002	0.000	0.000
gradient							
constant							

Table 16.3 R-squared and significance values for association between peak SI during reaching across to the opposite side and independent variables.

independent variable	age	age group	gender	mass	height	lower leg length	dominant hand
R^2	0.001	0.001	0.010	0.027	0.005	0.021	0.001
t_m	0.865	0.815	0.545	0.320	0.665	0.382	0.835
t_c	0.578	0.788	0.147	0.446	0.725	0.444	0.527
gradient							
constant							

Table 16.4 R-squared and significance values for association between mean SI during sitting after reaching across to the opposite side and independent variables.

independent variable	age	age group	gender	mass	height	lower leg length	dominant hand
R^2	0.006	0.006	0.126	0.024	0.005	0.045	0.015
t_m	0.641	0.637	0.025	0.334	0.678	0.197	0.452
t_c	0.000	0.000	0.000	0.000	0.033	0.001	0.000
gradient			0.958				
constant			6.880				

Table 16.5 R-squared and significance values for association between time taken to reach across to the opposite side and independent variables.

16.3 Hemiplegic subjects

16.3.1 Baseline measurement (week 0)

The distribution of the symmetry and time variables from the hemiplegic subjects during the first test week (week 0) can be compared with the results from the healthy subjects. The distribution of the peak SI during reaching across to the opposite side, the mean SI after reaching, and the time taken to reach are illustrated in Figure 16.15, Figure 16.17 and Figure 16.19. The distributions of the same variables from the healthy subjects are provided in Figure 16.14, Figure 16.16 and Figure 16.18 to allow comparison. The median and percentile values are listed in Table 16.6.

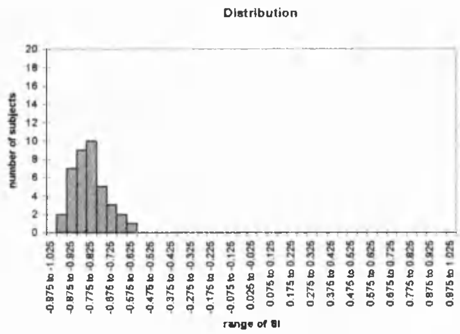


Figure 16.14 Distribution of peak symmetry index during reaching across to the opposite side for healthy subjects (young and elderly combined).

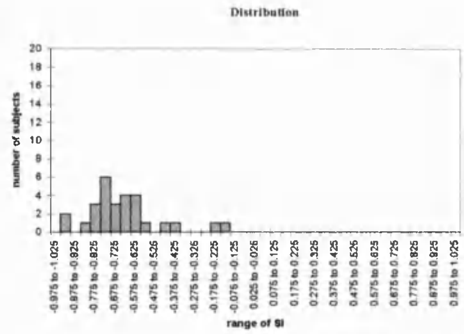


Figure 16.15 Distribution of peak symmetry index during reaching across to the opposite side for hemiplegic subjects during week 0 (control and practice combined).

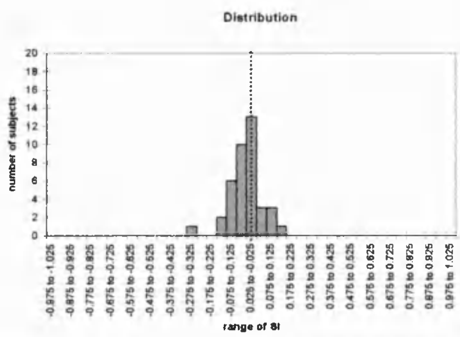


Figure 16.16 Distribution of mean symmetry index after reaching across to the opposite side for healthy subjects (young and elderly combined).

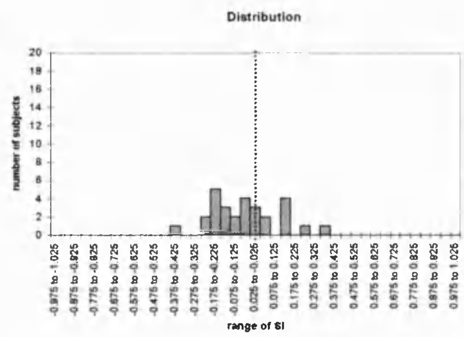


Figure 16.17 Distribution of mean symmetry index after reaching across to the opposite side for hemiplegic subjects during week 0 (control and practice combined).

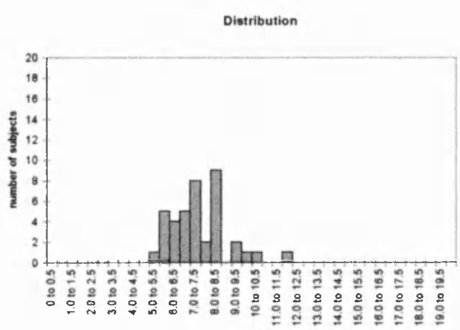


Figure 16.18 Distribution of time taken to reach across to the opposite side for healthy subjects (young and elderly combined).

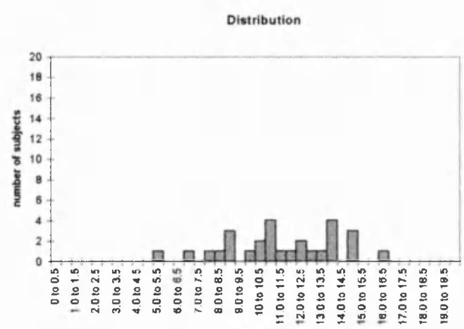


Figure 16.19 Distribution of time taken to reach across to the opposite side for hemiplegic subjects during week 0 (control and practice combined).

	Peak SI during reaching (SI)		Mean SI after reaching (SI)		Mean time to reach (s)	
	healthy	hemiplegic	healthy	hemiplegic	healthy	hemiplegic
median	-0.813	-0.688	-0.021	-0.064	7.360	11.107
25th percentile	-0.770	-0.608	0.013	0.037	6.453	9.455
75th percentile	-0.863	-0.774	-0.050	-0.178	8.233	13.592
interquartile range	0.094	0.166	0.063	0.216	1.780	4.137
5th percentile	-0.671	-0.280	0.111	0.237	5.750	6.976
95th percentile	-0.924	-0.923	-0.130	-0.257	9.582	14.735
90% range	0.254	0.642	0.241	0.494	3.832	7.758

Table 16.6 Medians and percentiles for reaching across to the opposite side. Healthy and hemiplegic subjects.

The distribution of the peak SI during reaching across to the opposite side was centred around a higher (less negative) point on the SI and had a greater variation for the hemiplegic subjects than for the healthy subjects. The median peak SI for the hemiplegic subjects was higher (more negative) than the 25th percentile for the healthy subjects, demonstrating that there was considerable difference between the distribution of the healthy and hemiplegic subjects. The variation between the peak symmetry indices of the hemiplegic subjects was greater than the variation between the healthy subjects. The distribution of the mean SI during sitting after reaching across to the opposite side was centred on a point less than 0 for both the healthy and hemiplegic subjects. The point was more negative for the hemiplegic subjects (-0.064) than for the healthy subjects (-0.021). The time taken to reach across to the opposite side was considerably longer for the hemiplegic subjects (11.1s) than the healthy subjects (7.4s), with the median values for the hemiplegic subjects being greater than the 95th percentile for the healthy subjects. The interquartile and 90% range for the time taken to reach across to the opposite side for the hemiplegic subjects were more than double that of the healthy subjects.

16.3.2 Control and practice groups

The relatively low number of subjects in the control and practice groups, the decrease in numbers over the test weeks due to patient discharge, and the relatively large variation between individual subjects, prevented the use of statistical tests to compare the control group and practice group results. Subsequently, comparison between the control group and practice group results was carried out with the use of descriptive statistics. The median, percentiles and interquartile and 90% ranges of the symmetry and time data are shown in Table 16.6 - Table 16.11. The median and quartile ranges of the symmetry data are shown graphically in Figure 16.20, Figure 16.21 and Figure 16.22.

Control group versus healthy subjects

The median peak symmetry during reaching across to the opposite side for the control subjects was slightly less than the median value for the healthy subjects throughout the test weeks. On all except one test week (week 2) the control group median peak SI was with out the healthy subject interquartile range; on all test weeks the control group median peak SI fell within the healthy subject 90% range.

The median values of the mean SI during sitting after reaching across to the opposite side for the control group remained fairly close to the values for the healthy subjects. During all test weeks the median values of the mean SI during sitting after reaching for the control group subjects was within the 90% range for the healthy subjects, which was a narrow band due to the small degree of variation between healthy subjects. The 90% range for the control group subjects was considerably larger than that of the healthy subjects.

The time taken to reach across to the opposite side by the control group subjects was greater than the time taken by the healthy subjects. The median value for the time taken was greater than the 95^{th} percentile for the healthy subjects by the control group on all test weeks.

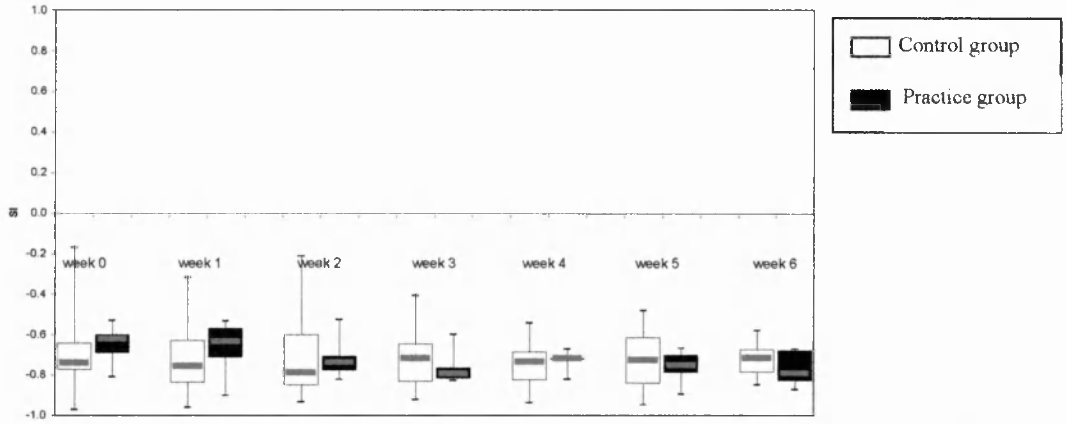


Figure 16.20 Medians, interquartile ranges and ranges of peak SI during reaching across to the opposite side by control and practice group subjects.

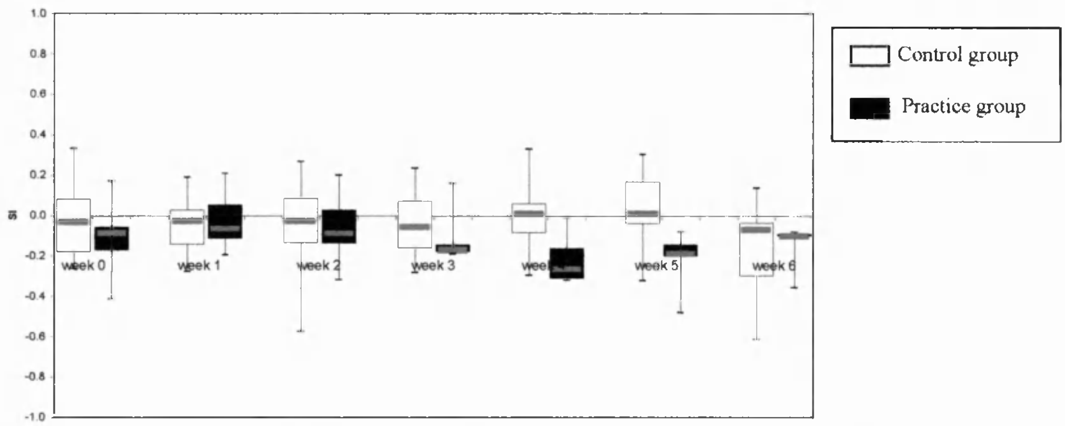


Figure 16.21 Medians, interquartile ranges and ranges of mean SI after reaching across to the opposite side by control and practice group subjects.

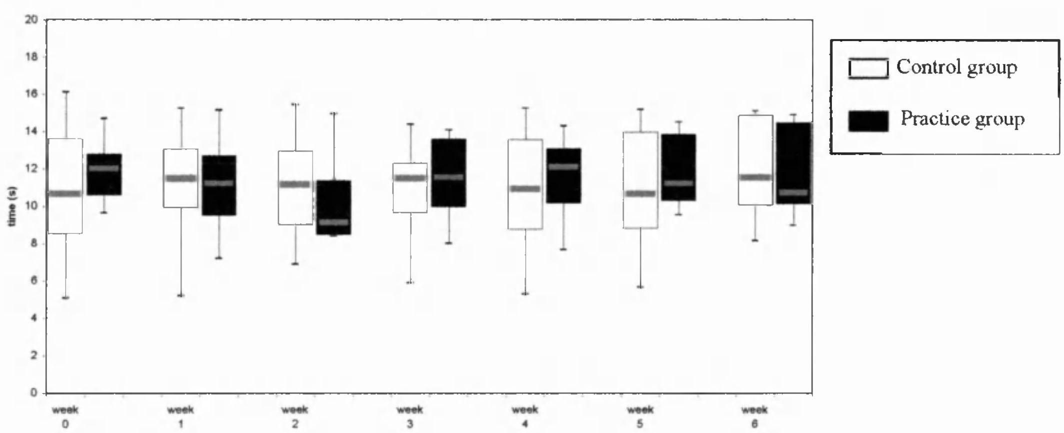


Figure 16.22 Medians, interquartile ranges and ranges of time taken to reach across to the opposite side by control and practice group subjects.

	healthy	week 0	week 1	week 2	week 3	week 4	week 5	week 6
median	-0.81	-0.74	-0.76	-0.79	-0.72	-0.73	-0.72	-0.71
25th percentile	-0.77	-0.64	-0.63	-0.60	-0.64	-0.68	-0.61	-0.67
75th percentile	-0.86	-0.77	-0.84	-0.85	-0.83	-0.82	-0.84	-0.79
interquartile range	0.09	0.13	0.21	0.25	0.19	0.14	0.23	0.12
5th percentile	-0.67	-0.20	-0.46	-0.34	-0.45	-0.55	-0.55	-0.59
95th percentile	-0.92	-0.97	-0.91	-0.91	-0.90	-0.91	-0.91	-0.84
90% range	0.25	0.77	0.45	0.57	0.45	0.35	0.36	0.25

Table 16.7 Medians and percentiles for peak SI during reaching across to the opposite side. Control group subjects (SI).

	healthy	week 0	week 1	week 2	week 3	week 4	week 5	week 6
median	-0.81	-0.62	-0.64	-0.74	-0.79	-0.72	-0.75	-0.79
25th percentile	-0.77	-0.60	-0.57	-0.70	-0.76	-0.71	-0.70	-0.68
75th percentile	-0.86	-0.69	-0.71	-0.78	-0.81	-0.72	-0.79	-0.83
interquartile range	0.09	0.09	0.15	0.07	0.05	0.00	0.09	0.15
5th percentile	-0.67	-0.56	-0.54	-0.58	-0.64	-0.68	-0.67	-0.67
95th percentile	-0.92	-0.80	-0.84	-0.81	-0.82	-0.80	-0.87	-0.86
90% range	0.25	0.24	0.30	0.23	0.19	0.12	0.20	0.19

Table 16.8 Medians and percentiles for peak SI during reaching across to the opposite side. practice group subjects (SI).

	healthy	week 0	week 1	week 2	week 3	week 4	week 5	week 6
median	-0.02	-0.03	-0.03	-0.03	-0.06	0.01	0.01	-0.07
25th percentile	0.01	0.08	0.03	0.09	0.07	0.06	0.17	-0.04
75th percentile	-0.05	-0.18	-0.14	-0.14	-0.16	-0.09	-0.04	-0.30
interquartile range	0.06	0.26	0.17	0.22	0.23	0.15	0.21	0.26
5th percentile	0.11	0.28	0.12	0.14	0.20	0.23	0.27	0.13
95th percentile	-0.13	-0.25	-0.28	-0.28	-0.26	-0.28	-0.26	-0.51
90% range	0.24	0.53	0.40	0.43	0.45	0.52	0.53	0.64

Table 16.9 Medians and percentiles for mean SI after reaching across to the opposite side. Control group subjects (SI).

	healthy	week 0	week 1	week 2	week 3	week 4	week 5	week 6
median	-0.02	-0.09	-0.07	-0.09	-0.17	-0.27	-0.19	-0.10
25th percentile	0.01	-0.06	0.05	0.03	-0.14	-0.16	-0.14	-0.09
75th percentile	-0.05	-0.17	-0.11	-0.14	-0.18	-0.31	-0.20	-0.10
interquartile range	0.06	0.12	0.17	0.17	0.04	0.15	0.06	0.01
5th percentile	0.11	0.12	0.19	0.18	0.09	-0.04	-0.09	-0.08
95th percentile	-0.13	-0.32	-0.17	-0.26	-0.19	-0.32	-0.43	-0.31
90% range	0.24	0.44	0.36	0.43	0.27	0.28	0.33	0.22

Table 16.10 Medians and percentiles for mean SI after reaching across to the opposite side. Practice group subjects (SI).

	healthy	week 0	week 1	week 2	week 3	week 4	week 5	week 6
median	7.36	10.65	11.48	11.16	11.49	10.92	10.67	11.53
25th percentile	6.45	8.55	9.91	9.00	9.66	8.75	8.79	10.06
75th percentile	8.23	13.64	13.08	12.99	12.33	13.56	13.99	14.88
interquartile range	1.78	5.08	3.17	3.99	2.67	4.81	5.20	4.83
5th percentile	5.75	6.39	5.94	7.36	7.30	6.75	6.17	8.49
95th percentile	9.58	14.89	14.79	13.76	13.61	14.94	14.70	15.10
90% range	3.83	8.49	8.86	6.40	6.30	8.18	8.53	6.61

Table 16.11 Medians and percentiles for time taken to reach across to the opposite side. Control group subjects (s).

	healthy	week 0	week 1	week 2	week 3	week 4	week 5	week 6
median	7.36	11.99	11.20	9.10	11.53	12.07	11.19	10.71
25th percentile	6.45	10.58	9.50	8.47	9.94	10.15	10.28	10.11
75th percentile	8.23	12.79	12.73	11.37	13.59	13.10	13.85	14.51
interquartile range	1.78	2.21	3.23	2.90	3.65	2.95	3.57	4.40
5th percentile	5.75	9.84	7.85	8.40	8.45	8.16	9.68	9.18
95th percentile	9.58	14.36	15.13	14.85	14.03	14.05	14.37	14.82
90% range	3.83	4.52	7.28	6.45	5.58	5.90	4.69	5.64

Table 16.12 Medians and percentiles for time taken to reach across to the opposite side. Practice group subjects (s).

Practice group versus healthy subjects

The peak symmetry value for the practice group subjects was less than that of the healthy subjects on all test weeks. The practice group median peak SI was with out the healthy subject 90% range during test weeks 0 and 1. During test weeks 2-6 the practice group median peak SI fell within the healthy subject 90% range. On two weeks (week 3 and 6) the practice group median peak SI was within the healthy subject interquartile range.

The median value of the mean SI during sitting after reaching across to the opposite side for the practice group subjects was always lower (more negative) for the practice group subjects than for the healthy subjects. During test weeks 0, 1, 2 and 6 the median value for the mean SI during sitting after reaching for the practice group subjects was within the healthy subject 90% range. However during test weeks 3, 4 and 5 the median value for the practice group subjects was less than that of the healthy subject 95th percentile.

The time taken to reach across to the opposite side by the practice group subjects was greater than the time taken by the healthy subjects. The median value for the time taken by the practice group was greater than the 95th percentile for the healthy subjects on all test weeks, with the exception of the time taken during test week 2 which fell just within the healthy subject 90% range.

Control versus practice group

During test weeks 0 and 1 the peak SI during reaching across to the opposite side for the practice group was slightly less (less negative) than that of the control group. However during test weeks 2-6 the peak symmetry indices for the control group and practice group were similar. The interquartile and 90% range of the peak SI for both the control and practice groups was considerably greater in magnitude than that of the healthy subjects; the increased magnitude of variation was due to a shift in the hemiplegic subject data toward more positive symmetry values. There was no obvious change in the peak SI for the control group subjects throughout the test weeks. With the exception of the increase in values between week 1 and week 2 for the practice group, neither was there an obvious change in the peak SI for the practice group subjects over the test weeks.

The mean SI during sitting after reaching was similar for the control group and practice group during test weeks 0, 1 and 2. However, during weeks 3 – 6 the median value of the mean SI during sitting after reaching for the practice group was less than that of the control group. Additionally, during these latter weeks, the interquartile and 90% range for the mean SI during sitting after reaching across to the opposite side for the practice group subjects was notably less than that for the control group subjects. Comparing the pattern of mean SI data after reaching to the same side and reaching across to the opposite side (Figure 15.21 and Figure 16.21) indicated a remarkable similarity in the mean symmetry values for the practice group subjects during reaching to the same side and reaching across to the opposite side.

The time taken to reach across to the opposite side by the control and practice group subjects was greater than the time taken by the healthy subjects on all test weeks. The time taken by the control and practice group subjects was similar and demonstrated no trends or patterns over the test weeks.

16.3.3 Effect of discharge on group results

The numbers of subjects in both the control and practice groups decreased over the test weeks as subjects were discharged from the trial. It was therefore possible that observing the results for the groups of subjects may have masked trends in the outcome variables of individual subjects. The results of the subjects who had measurements taken on all 7 test weeks, and the results of subjects who were discharged home prior to week 6, could provide information pertaining to trends in the data over time. Table 16.13 - Table 16.18 display the medians and interquartile ranges for the outcome variables for control and practice group subjects who were not discharged during, who were discharged home and who were discharged for other reasons during the test period. Figure 16.23, Figure 16.24 and Figure 16.25 illustrate the median, interquartile range and range of the outcome measures for the control and practice group subjects who were not discharged during the test period.

Comparing the graph of the median and ranges of the peak SI during reaching across to the opposite side for the whole group (Figure 16.20) and that for the subjects who were not discharged home during the test period (Figure 16.23) did not reveal any observable differences. The median values for the peak SI during reaching across to the opposite side for the control group subjects revealed that the median values for subjects who were not discharged during the test period were lower than the median values for the subjects who were discharged during the test period. There was no observable difference between the median values for the peak SI during reaching across to the opposite side for practice group subjects with different discharge statuses.

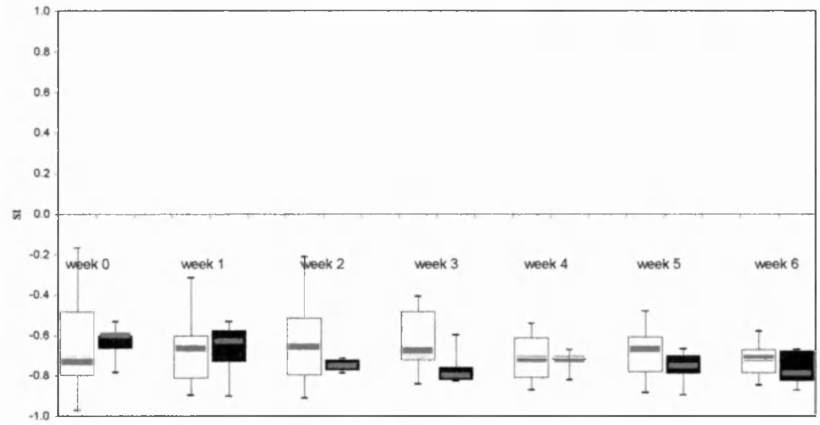


Figure 16.23 Median, interquartile range and range of peak symmetry during reaching across to the opposite side for hemiplegic subjects completing 7 test weeks.

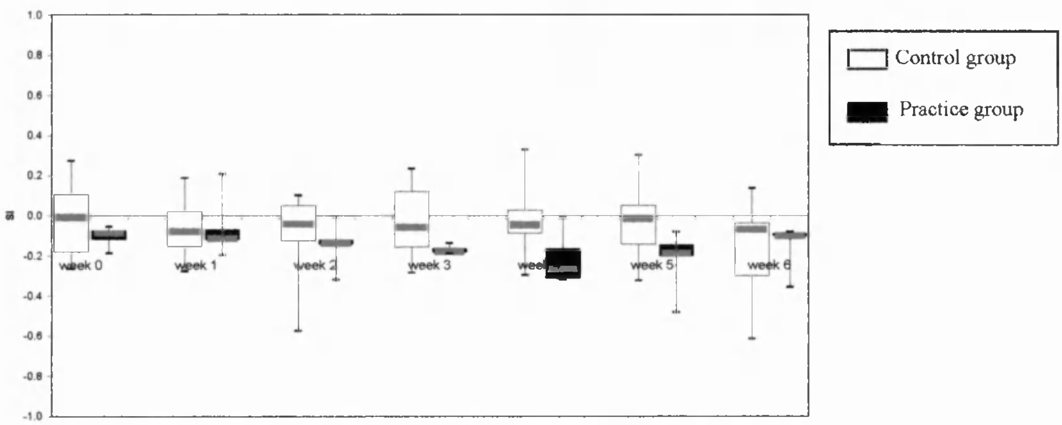


Figure 16.24 Median, interquartile range and range of mean symmetry after reaching to the opposite side for hemiplegic subjects completing 7 test weeks.

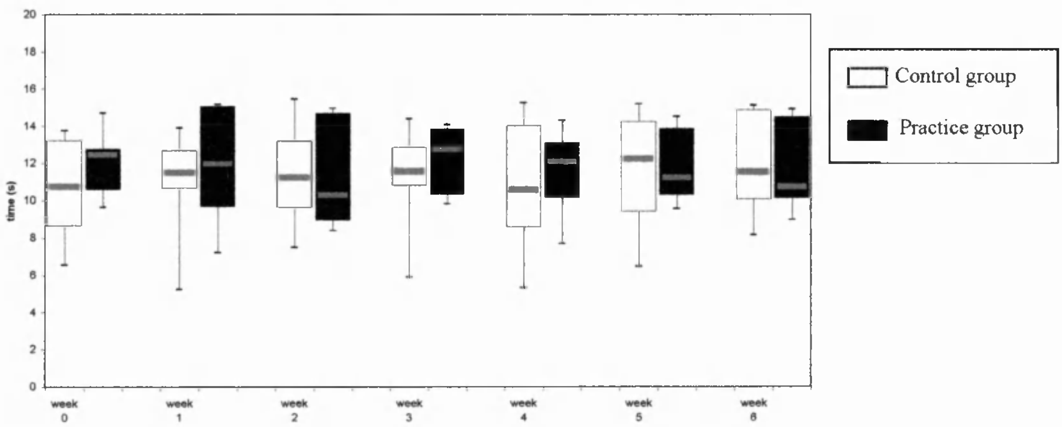


Figure 16.25 Median, interquartile range and range of time taken to reach across to the opposite side for hemiplegic subjects completing 7 test weeks.

Group	Discharge status	week 0	week 1	week 2	week 3	week 4	week 5	week 6
control	not discharged	-0.730	-0.664	-0.655	-0.674	-0.718	-0.667	-0.712
	discharged home	-0.751	-0.796	-0.824	-0.821	-0.807	-0.808	
	discharged other	-0.685	-0.738	-0.935	-0.895			
practice	not discharged	-0.601	-0.629	-0.752	-0.798	-0.717	-0.752	-0.789
	discharged home	-0.651	-0.593	-0.673	-0.787			
	discharged other	-0.716	-0.707	-0.681				

Table 16.13 Median values of peak symmetry during reaching across to the opposite side for control and practice groups according to discharge status (SI).

Group	Discharge status	week 0	week 1	week 2	week 3	week 4	week 5	week 6
control	not discharged	0.318	0.213	0.281	0.242	0.196	0.174	0.115
	discharged home	0.098	0.088	0.095	0.148	0.191	0.173	
	discharged other	0.179	0.223	0.000	0.000			
practice	not discharged	0.063	0.155	0.052	0.064	0.005	0.088	0.150
	discharged home	0.040	0.048	0.149	0.000			
	discharged other	0.095	0.000	0.000				

Table 16.14 Interquartile range values for peak symmetry during reaching across to the opposite side for control and practice groups according to discharge status (SI).

Group	Discharge status	week 0	week 1	week 2	week 3	week 4	week 5	week 6
control	not discharged	-0.008	-0.079	-0.040	-0.056	-0.045	-0.015	-0.069
	discharged home	-0.136	-0.049	-0.035	-0.093	0.090	0.164	
	discharged other	0.138	0.039	0.267	0.005	-0.084		
practice	not discharged	-0.089	-0.114	-0.135	-0.178	-0.267	-0.188	-0.100
	discharged home	-0.002	0.049	0.037	0.159			
	discharged other	-0.183	0.018	0.199				

Table 16.15 Median values of mean symmetry after reaching across to the opposite side for control and practice groups according to discharge status (SI).

Group	Discharge status	week 0	week 1	week 2	week 3	week 4	week 5	week 6
control	not discharged	0.286	0.176	0.177	0.276	0.115	0.195	0.263
	discharged home	0.117	0.093	0.216	0.191	0.056	0.066	
	discharged other	0.160	0.032	0.000	0.000	0.000		
practice	not discharged	0.045	0.049	0.021	0.019	0.149	0.056	0.011
	discharged home	0.171	0.114	0.100	0.000			
	discharged other	0.230	0.000	0.000				

Table 16.16 Interquartile range values for mean symmetry after reaching across to the opposite side for control and practice groups according to discharge status (SI).

Group	Discharge status	week 0	week 1	week 2	week 3	week 4	week 5	week 6
control	not discharged	10.740	11.490	11.243	11.553	10.573	12.233	11.530
	discharged home	12.042	10.147	9.400	11.173	10.920	8.960	
	discharged other	7.787	11.200	11.427	9.440			
practice	not discharged	12.427	11.947	10.260	12.733	12.073	11.193	10.707
	discharged home	10.760	9.827	8.857	8.000			
	discharged other	12.920	11.807	8.480				

Table 16.17 Median values of time taken to reach across to the opposite side for control and practice groups according to discharge status (s).

Group	Discharge status	week 0	week 1	week 2	week 3	week 4	week 5	week 6
control	not discharged	4.578	2.027	3.593	2.080	5.467	4.832	4.825
	discharged home	3.954	2.518	2.985	1.913	1.383	3.557	
	discharged other	4.833	4.053	0.000	0.000			
practice	not discharged	2.207	5.433	5.747	3.560	2.953	3.573	4.400
	discharged home	0.607	0.760	0.410	0.000			
	discharged other	0.927	0.000	0.000				

Table 16.18 Interquartile range values for time taken to reach across to the opposite side for control and practice groups according to discharge status (s).

The graph for the mean SI during sitting after reaching across to the opposite side for the whole group of hemiplegic subjects (Figure 16.21) and the hemiplegic subjects who completed 7 test weeks (Figure 16.24) both demonstrate a similar pattern. The data for the median value of the mean SI during sitting after reaching across to the opposite side for the control group demonstrates that there was no difference in the pattern of the results from control group subjects who were or were not discharged. For the practice group subjects, the median value of the mean SI during sitting after reaching across to the opposite side tended to be higher for subjects who were discharged than for subjects who were not discharged.

As in the whole group results, there was no observable trend in the time taken to reach across to the opposite side by control or practice group subjects over the test period. The median times taken by subjects with different discharge status demonstrated little difference between control group subjects who were or were not discharged. Practice group subjects who were discharged home can be observed to take less time to reach across to the opposite side than subjects who were not discharged.

Although small differences were observed between the median values of the subjects who were discharged and those who were not these have to be viewed relative to the magnitude of the interquartile ranges. While these small differences did occur, the whole group pattern of results was similar to that of the results from subjects completing 7 test weeks. This indicates that the effect of discharge on the pattern of the outcome variable observed for reaching across to the opposite side was minimal.

16.3.4 Classification of ability

Using the definition of 'normal' values that was previously stated, the proportion of hemiplegic subjects with symmetry and time data within the normal range was determined. The proportions of control and practice group subjects with the outcome variables falling within the normal range are illustrated in Table 16.19 - Table 16.21 and in Figure 16.26 - Figure 16.31.

At the time of the baseline measurement (week 0), a higher proportion of control group subjects (53%) than practice group subjects (33%) had normal peak SI during reaching across to the opposite side. During test week 1 the proportional difference remained similar. However, in test week 2-6 the proportion of practice group subjects achieving normal peak symmetry increased, and was greater than that of the control group subjects. Although a higher proportion of the practice group subjects were observed to achieve normal peak symmetry, the Chi-squared test demonstrated that there was no significant difference between the ability of the practice and control group.

No pattern can be observed in the proportion of control and practice subjects able to achieve normal mean symmetry of weight distribution during sitting after reaching across to the opposite side. However the proportion of practice group subjects achieving normal mean SI during sitting after reaching decreased and was lower than that of the control group subjects during test weeks 2-5. During test week 3 the difference between the ability of the control and practice group neared significance ($Chi^2 = 0.067$) and during test week 4 the difference was statistically significant ($Chi^2 = 0.027$).

The proportion of hemiplegic subjects able to achieve reaching across to the opposite side with the normal time was low throughout the test period. There were no observable differences between the ability of the control and practice group subjects, or in the pattern of ability of the groups over the test weeks.

	Control			Practice			
	unable	abnormal	normal	unable	abnormal	normal	*Chi²*
Week 0	0%	47%	53%	0%	67%	33%	*0.339*
Week 1	0%	44%	56%	0%	63%	38%	*0.395*
Week 2	0%	35%	65%	0%	13%	88%	*0.236*
Week 3	0%	27%	73%	0%	17%	83%	*0.728*
Week 4	0%	33%	67%	0%	0%	100%	*0.136*
Week 5	0%	43%	57%	0%	20%	80%	*0.363*
Week 6	0%	30%	70%	0%	20%	80%	*0.680*

Table 16.19 Proportion of control and practice group subjects achieving normal peak symmetry during reaching across to the opposite side, and the Chi² statistic for the difference between the ability of the control and practice group subjects.

	Control			Practice			
	unable	abnormal	normal	unable	abnormal	normal	*Chi²*
Week 0	0%	63%	37%	0%	44%	56%	*0.350*
Week 1	0%	44%	56%	0%	38%	63%	*0.741*
Week 2	0%	47%	53%	0%	63%	38%	*0.471*
Week 3	0%	60%	40%	0%	100%	0%	*0.067*
Week 4	0%	25%	75%	0%	80%	20%	*0.027*
Week 5	0%	57%	43%	0%	80%	20%	*0.363*
Week 6	0%	50%	50%	0%	20%	80%	*0.264*

Table 16.20 Proportion of control and practice group subjects achieving normal mean symmetry after reaching across to the opposite side, and the Chi² statistic for the difference between the ability of the control and practice group subjects.

	Control			Practice			
	unable	abnormal	normal	unable	abnormal	normal	*Chi²*
Week 0	0%	68%	32%	0%	100%	0%	*0.057*
Week 1	0%	83%	17%	0%	75%	25%	*0.619*
Week 2	0%	65%	35%	0%	38%	63%	*0.201*
Week 3	0%	73%	27%	0%	83%	17%	*0.728*
Week 4	0%	67%	33%	0%	80%	20%	*0.573*
Week 5	0%	71%	29%	0%	80%	20%	*0.709*
Week 6	0%	80%	20%	0%	80%	20%	*1.000*

Table 16.21 Proportion of control and practice group subjects achieving normal time to reach across to the opposite side, and the Chi² statistic for the difference between the ability of the control and practice group subjects.

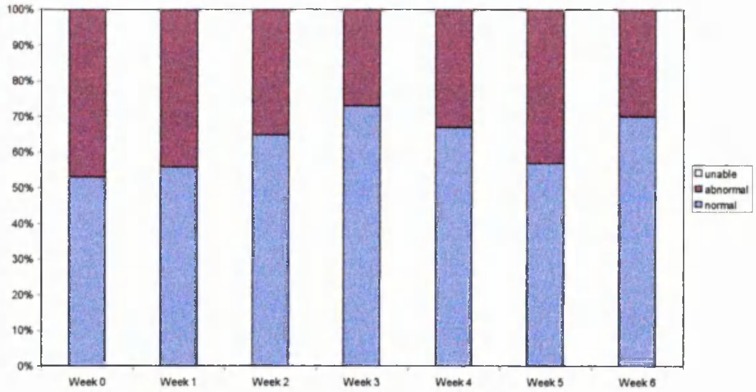


Figure 16.26 Proportion of control group subjects achieving normal peak symmetry index during reaching across to the opposite side on different test weeks.

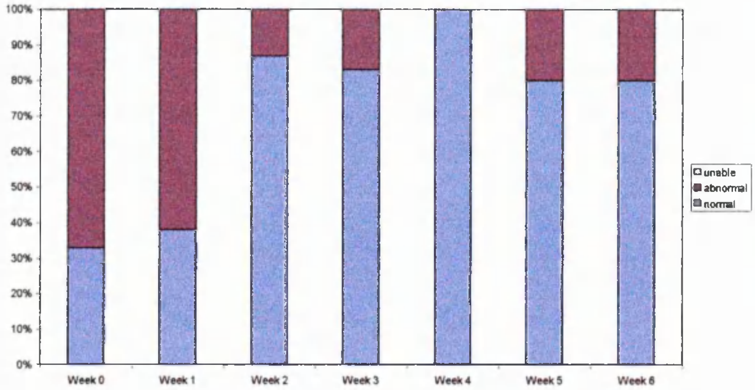


Figure 16.27 Proportion of practice group subjects achieving normal peak symmetry index during reaching across to the opposite side on different test weeks.

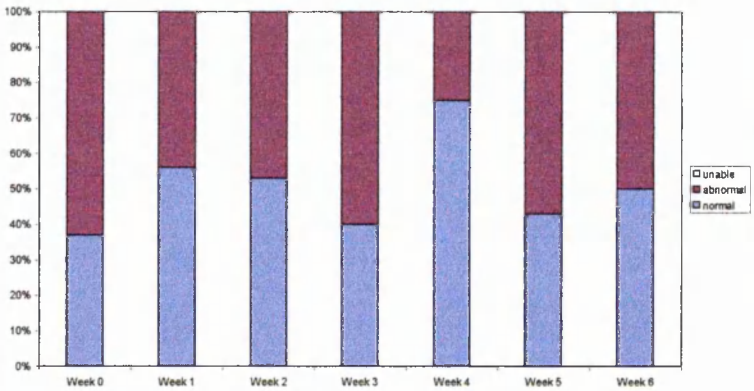


Figure 16.28 Proportion of control group subjects achieving normal mean symmetry index after reaching across to the opposite side on different test weeks.

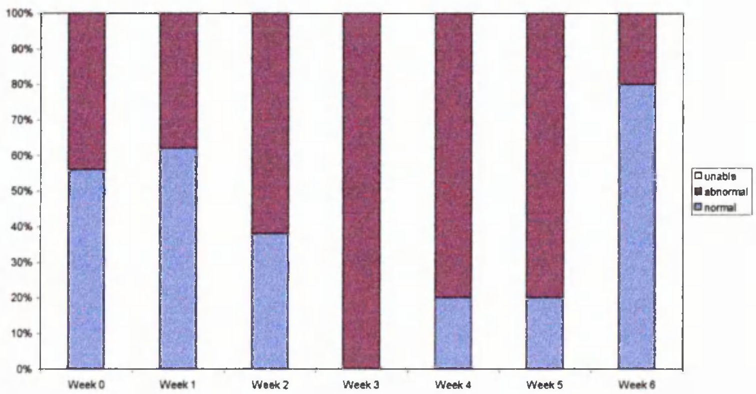


Figure 16.29 Proportion of practice group subjects achieving normal mean symmetry index after reaching across to the opposite side on different test weeks.

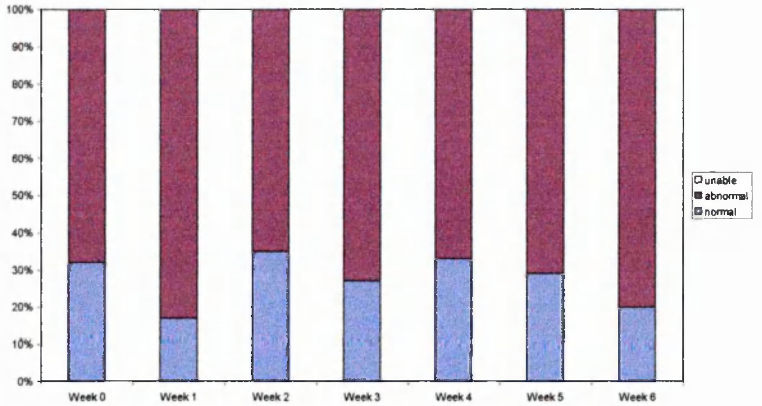


Figure 16.30 Proportion of control group subjects achieving normal time to reach across to the opposite side on different test weeks.

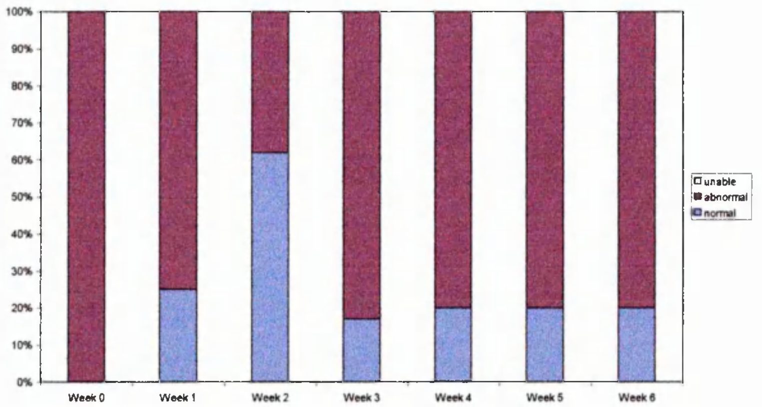


Figure 16.31 Proportion of practice group subjects achieving normal time to reach across to the opposite side on different test weeks.

The number of control and practice group subjects whose ability to reaching across to the opposite side changes, relative to the "normal", between their first and last test of reaching to the same side is shown in Table 16.22 - Table 16.24. As was found for the changes in the ability to achieve normal peak SI during reaching to the same side, the ability of over 50% of the control and practice group to achieve normal peak SI during reaching across to the opposite side did not change. Of those subjects whose ability did change, a greater proportion improved than deteriorated; the ability of none of the practice subjects to achieve normal peak symmetry deteriorated. 100% of the practice group subjects demonstrated no change between the first and last test in the ability to achieve normal mean symmetry of weight distribution during sitting after reaching across to the opposite side. The pattern for the ability to achieve normal mean SI after reaching across to the opposite side was different for the control group subjects; 37% of whom improved between the first and last test. Over 50% of control and practice group subjects demonstrated times to reach across to the opposite side which were with out normal time limits during the first and final test of reaching. A higher proportion of practice group subjects (0%+44%+0% = 44%) than control group subjects (0%+11%+11% = 22%) achieved normal time to reach during the test period.

Ability at final measurement

Initial ability	Control unable	Control abnormal	Control normal	Practice unable	Practice abnormal	Practice normal
Unable	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
Abnormal	0 (0%)	4 (21%)	5 (26%)	0 (0%)	3 (33%)	3 (33%)
Normal	0 (0%)	2 (11%)	8 (42%)	0 (0%)	0%	3 (33%)

Table 16.22 Number (and percentage) of control and practice group subjects with ability to achieve normal peak symmetry index during reaching across to the opposite side changing between the initial and final measurement.

Ability at final measurement

Initial ability	Control unable	Control abnormal	Control normal	Practice Unable	Practice abnormal	Practice normal
Unable	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
Abnormal	0 (0%)	5 (26%)	7 (37%)	0 (0%)	4 (44%)	0 (0%)
Normal	0 (0%)	4 (21%)	3 (16%)	0 (0%)	0 (0%)	5 (56%)

Table 16.23 Number (and percentage) of control and practice group subjects with ability to achieve normal mean symmetry of weight distribution after reaching across to the opposite side changing between the initial and final measurement.

Ability at final measurement

Initial ability	Control unable	Control abnormal	Control normal	Practice Unable	Practice abnormal	Practice normal
Unable	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
Abnormal	0 (0%)	11 (58%)	2 (11%)	0 (0%)	5 (56%)	4 (44%)
Normal	0 (0%)	4 (21%)	2 (11%)	0 (0%)	0 (0%)	0 (0%)

Table 16.24 Number (and percentage) of control and practice group subjects with ability to achieve normal time during reaching across to the opposite side changing between the initial and final measurement.

17. Results: Functional ability

17.1 Comparing functional tasks

17.1.1 Healthy subjects

Previous chapters presented the data derived from the measurement of the symmetry of weight distribution during sitting, standing, rising to stand, sitting down, reaching to the same side and reaching across to the opposite side. Each functional task was analysed and reported individually. In order to investigate whether there was any relationship between the symmetry and time variables from the different tasks Pearson's correlation coefficient was determined for the association between any two variables. Pearson's r value provides a measure of the extent to which paired scores are correlated. Each subject had 14 different measures of outcome (symmetry and time variables from different functions). The maximum number of pairs that could be created from the 14 scores was 78 pairs. Pearson's r values for the associations between the different pairs of values are provided in Table 17.1.

Correlation coefficient	sit	std	RTSon	RTSoff	RTStime	SDoff	SDon	SDtime	RSpeak	RSafter	RStime	RApeak	RAafter	RAtime
sit	1													
std	0.08	1												
RTSon	0.69	0.26	1											
RTSoff	0.05	0.41	0.00	1										
RTStime	0.08	0.06	0.00	0.14	1									
SDoff	0.16	0.92	0.27	0.45	0.05	1								
SDon	0.58	0.17	0.78	0.08	0.10	0.23	1							
SDtime	0.27	0.06	0.24	0.14	0.60	0.11	0.18	1						
RSpeak	0.30	0.00	0.23	0.06	0.06	0.11	0.21	0.08	1					
RSafter	0.10	0.08	0.00	0.03	0.03	0.11	0.10	0.18	0.15	1				
RStime	0.10	0.10	0.31	0.20	0.06	0.16	0.26	0.13	0.17	0.39	1			
RApeak	0.15	0.20	0.30	0.09	0.29	0.20	0.24	0.17	0.46	0.26	0.05	1		
RAafter	0.11	0.00	0.08	0.24	0.11	0.03	0.05	0.32	0.20	0.56	0.38	0.18	1	
RAtime	0.16	0.22	0.28	0.05	0.00	0.22	0.29	0.39	0.22	0.26	0.51	0.00	0.29	1

Table 17.1 Pearson's r value for association between outcome variables from measured functions. Healthy subjects. (Key to abbreviations in Appendix K).

The r value depicts the strength of the association between variables. Currier (1990) proposed that correlation coefficients from 0 - 0.69 indicate poor correlation; 0.70 – 0.79 fair association; 0.80 – 0.89 good association; and 0.90 – 0.99 high association. For the purposes of this study, an association of relevant strength was defined as the association occurring between two variables when the r value was greater than 0.70 ("fair" association, or 49% of variability accounted for) and when the significance levels of the gradient and constant of the regression equation have greater than 95% significance ($p<0.05$).

The correlation coefficients for the association between the symmetry of weight distribution during the seat-on phases of rising to stand and sitting down and between the symmetry of weight distribution during stance and the seat-off phase of sitting down were both greater than 0.70 (0.917 and 0.781 respectively). The significance levels of the gradient and constant of the regression equations for the association between these variables are provided in Table 17.2.

Regression equation	p (gradient)	p (constant)
SDoff = (0.95*std) + 0.01	0.000	0.225
SDon = (1.12*RTSon) + 0.01	0.000	0.052

Table 17.2 Regression equation and significance levels for the gradient and constant in the equation for associations between outcome variables of different functions with Pearson's r value > 0.70. Healthy subjects. (Key to abbreviations in Appendix K).

Although the significance level for the gradient of the regression equation was high ($p<0.05$), the significance level for the constant of the regression equation was greater than 0.05, for both associations. Thus, the association between these variables did not meet the criteria defined for an association of relevant strength for this study. There were therefore no relevant associations between the outcome variables for the healthy subjects.

17.1.2 Hemiplegic subjects

In the same manner as the investigation of associations between symmetry and time variables during the different functional tasks for the healthy subjects, Pearson's correlation coefficient was determined for the association between any two variables for the hemiplegic subjects. This process was carried out using all the results from control and practice group subjects from all weeks. The use of the combined data allowed the exploration of associations between functional activities in subjects with hemiplegia, regardless of treatment intervention or stage in rehabilitation. The Pearson's r values for the associations between the different pairs of values are provided in Table 17.3.

Correlation coefficient	sit	std	RTSon	RTSoff	RTStime	SDoff	SDon	SDtime	RSpeak	RSafter	RStime	RApeak	RAafter	RAtime
sit	1													
std	0.38	1												
RTSon	0.37	0.57	1											
RTSoff	0.25	0.67	0.49	1										
RTStime	0.13	0.23	0.32	0.29	1									
SDoff	0.32	0.78	0.68	0.65	0.27	1								
SDon	0.11	0.16	0.22	0.17	0.14	0.33	1							
SDtime	0.06	0.06	0.03	0.06	0.09	0.19	0.08	1						
RSpeak	0.18	0.18	0.34	0.33	0.46	0.29	0.31	0.08	1					
RSafter	0.18	0.21	0.05	0.03	0.21	0.11	0.48	0.06	0.45	1				
RStime	0.07	0.34	0.24	0.11	0.32	0.20	0.03	0.00	0.03	0.18	1			
RApeak	0.09	0.31	0.12	0.00	0.22	0.06	0.15	0.07	0.31	0.21	0.09	1		
RAafter	0.38	0.00	0.27	0.14	0.40	0.11	0.52	0.05	0.51	0.61	0.19	0.11	1	
RAtime	0.12	0.20	0.00	0.06	0.28	0.05	0.16	0.07	0.00	0.11	0.76	0.05	0.18	1

Table 17.3 Pearson's r value for association between outcome variables from measured functions. Hemiplegic subjects. (Key to abbreviations in Appendix K).

The correlation coefficients for the association between the symmetry of weight distribution during stance and during the seat-off phase of sitting down and between the time taken to reach to the same and reach across to the opposite sides were greater than 0.70 (0.78 and 0.76 respectively). The significance levels of the gradient and constant of the regression equations for the association between these variables are provided in Table 17.4. The significance level for the constant and gradient for both these regression equations were less than 0.05, meeting the defined criteria for an association of relevant strength. The regression lines for the association between these variables are displayed in Figure 17.1 and Figure 17.2.

Regression equation	p (gradient)	p (constant)
SDoff = (0.93*std) + 0.12	0.000	0.000
RAtime = (0.76*RStime) + 3.40	0.000	0.000

Table 17.4 Regression equation and significance levels for the gradient and constant in the equation for associations between outcome variables of different functions with Pearson's r value > 0.70. Hemiplegic subjects. (Key to abbreviations in Appendix K).

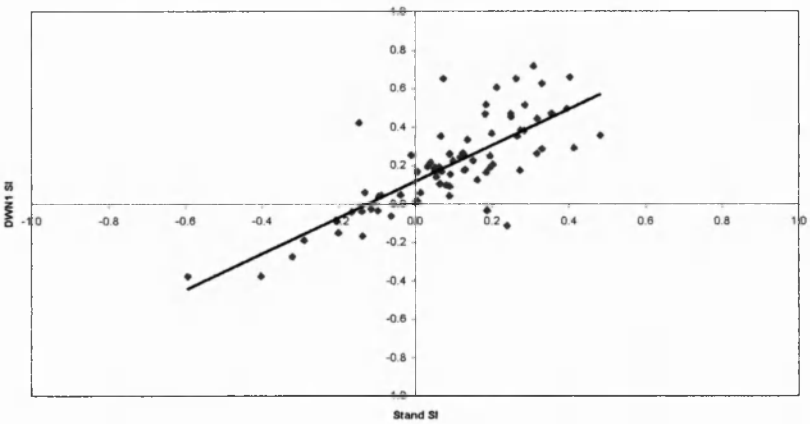


Figure 17.1 Association and regression line symmetry of weight distribution in standing against symmetry of weight distribution during seat-off phase of sitting down. Hemiplegic subjects.

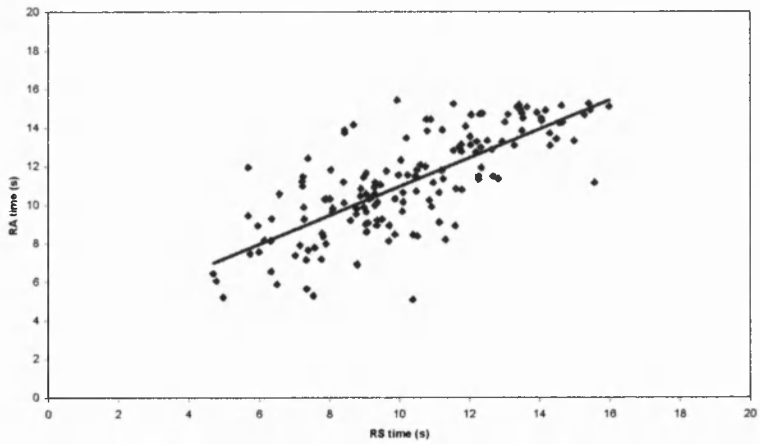


Figure 17.2 Association and regression line for time to reach to same side against time to reach across to the opposite side.

The data and graphs demonstrated that there was a positive association between the symmetry of weight distribution during stance and the symmetry of weight distribution during the seat-off phase for sitting down for subjects with hemiplegia. There was also a positive association between the time taken by subjects with hemiplegia to reach to the unaffected side and to reach across to the affected side.

17.2 Functional ability score

In the previous chapters (chapters 11-16), the ability of the hemiplegic subjects was determined by comparing the ability of hemiplegic subjects with the "normal" range for each outcome variable, for each individual function. The "normal range" was defined as being between the 5th and 95th percentiles of the healthy subject data for that variable. The ability of the hemiplegic subjects was classified as "unable", "abnormal" or "normal". "Unable" was assigned to subjects unable to perform the specified task. "Abnormal" was assigned to subjects who were able to perform the task, but for whom the measured outcome variables for that task were with out the normal range of the healthy subjects. "Normal" was assigned to subjects who had outcome variables falling within the normal range of the healthy subjects. While this classification system was useful in the investigation of the ability of hemiplegic subjects to execute specific functions, this system was limited to the exploration of the ability of hemiplegic subjects to perform individual tasks. The hemiplegic subjects were demonstrated to have a lack of ability in a number of different functional tasks. To assess the total functional ability of the hemiplegic subjects over the test weeks, the ability of each subject at each individual task was combined to give a total functional ability score (FAS).

The FAS was determined by assigning a score of 0 for unable, 1 for abnormal and 2 for normal for each of the 14 outcome variables. The 14 outcome variables included the symmetry measures during sitting, standing, rising to stand, sitting down, reaching to the same side and reaching across to the opposite side, and the time measures for rising to stand, sitting down, reaching to the same side and reaching across to the opposite side. The FAS gave a maximum score of 28.

17.2.1 Control and practice groups

The median, interquartile range and range of the FAS for the control and practice group subjects are displayed graphically in Figure 17.3. The values of the medians and percentiles are provided in Table 17.5 and Table 17.6. The median FAS increased from week 0 to week 2 for both the control and practice groups. During the subsequent weeks (weeks 3-6) there was no observable trend in the data for either the control or practice group subjects, with the median values remaining fairly similar.

During these weeks the median value for the control group was slightly higher than that for the practice group. At the baseline measure (week 0) the variation between subjects was very small; this was substantially greater during weeks 1-6, for both the control and practice groups. Although the median for the control group was slightly higher than that of the practice group during weeks 3-6, the percentile values remained similar with a large area of overlap in the interquartile range and range for the two groups.

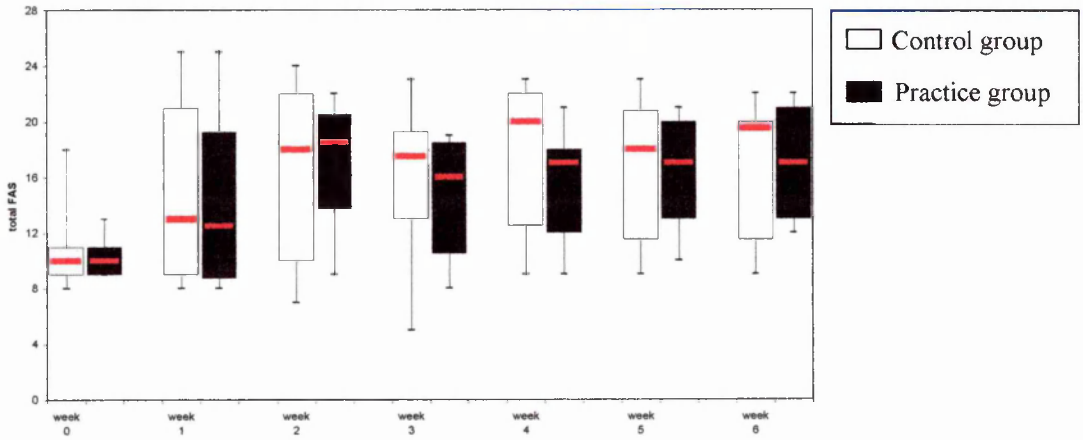


Figure 17.3 Medians, interquartile ranges and ranges of FAS for control and practice group subjects.

	week 0	week 1	week 2	week 3	week 4	week 5	week 6
median	10	13	18	17.5	20	18	19.5
25th percentile	9	9	10	13	12.5	11.5	11.5
75th percentile	11	21	22	19.25	22	20.75	20
interquartile range	2	12	12	6.25	9.5	9.25	8.5
5th percentile	8	8	8.6	8	9.7	9	9.45
95th percentile	14.4	23.3	22.4	21.5	23	22.35	21.55
90% range	6.4	15.3	13.8	13.5	13.3	13.35	12.1

Table 17.5 Medians and percentiles for total FAS. Control group subjects.

	week 0	week 1	week 2	week 3	week 4	week 5	week 6
median	9.5	12.5	18.5	16	17	17	17
25th percentile	9	8.75	13.75	10.5	12	13	13
75th percentile	11	19.25	20.5	18.5	18	20	21
interquartile range	2	10.5	6.75	8	6	7	8
5th percentile	9	8	9.35	8.25	9.6	10.6	12.2
95th percentile	12.2	24.3	22	19	20.4	20.8	21.8
90% range	3.2	16.3	12.65	10.75	10.8	10.2	9.6

Table 17.6 Medians and percentiles for total FAS. Practice group subjects.

17.2.2 Effect of discharge on functional ability score

As discussed in the earlier chapters, the number of subjects discharged over the test weeks could have potentially influenced the patterns and trends in the group results. One method that was used for investigating the possible effects of discharge on the group results involved the exploration of the results of the subjects who were not discharged during the test period. The results of the subjects who were not discharged during the test period were compared with the results of the subjects who were discharged home or discharged for other reasons during the test period. Figure 17.4 illustrates the medians, interquartile ranges and ranges of the FAS for the control and practice group subjects who were not discharged during the test period. Table 17.7 and Table 17.8 display the medians and interquartile ranges for the hemiplegic subjects according to discharge status.

Group	Discharge status	week 0	week 1	week 2	week 3	week 4	week 5	week 6
control	not discharged	10.5	10.5	11.5	14.5	16.5	18	19.5
	discharged home	10.5	21	21.5	19	23	18.5	
	discharged other	10	15.5	19	21			
practice	not discharged	9	9	15	15	17	17	17
	discharged home	12	20.5	21	19			
	discharged other	10	23	22				

Table 17.7 Median values of total FAS for control and practice groups according to discharge status.

Group	Discharge status	week 0	week 1	week 2	week 3	week 4	week 5	week 6
control	not discharged	1.75	6.75	11.25	8.75	8.75	10.5	8.5
	discharged home	3.75	6.75	3.25	2	1	3.25	
	discharged other	1	6.5	0	0			
Practice	not discharged	1	1	7	8	6	7	8
	discharged home	1	4.5	1	0			
	discharged other	1	0	0				

Table 17.8 Interquartile range values for total FAS for control and practice groups according to discharge status.

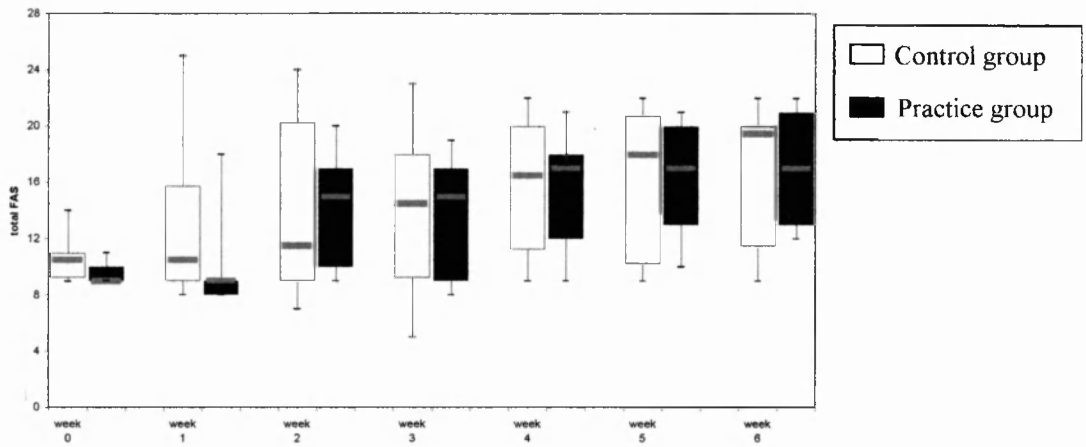


Figure 17.4 Medians, interquartile ranges and ranges of FAS for control and practice group subjects who completed 7 test weeks.

The median values for the control and practice group subjects increased between test week 1 and test week 4, for subjects who were not discharged. The median values of the FAS remained low during test weeks 0 and 1, and also altered little during test weeks 4, 5 and 6. This contrasts with the whole group result where the median FAS increased between test weeks 0 and 2, and changed only slightly in the subsequent weeks. The values of the median FAS for the control and practice group subjects who were discharged home or discharged for other reasons provide a possible explanation for the difference between the whole group result (Table 17.5 and Table 17.6) and the results from the subjects who were not discharged (Table 17.7). The median values from the subjects who were discharged increased more rapidly than those from the subjects not discharged.

17.2.3 Effect of ability to achieve tasks on functional ability score

The FAS allocated a score of 0 to subjects who were unable to achieve a task. A number of subjects were unable to perform standing, rising to stand and sitting down on some of the test weeks. A subject's ability to achieve stance, rising to stand and sitting down on each test week therefore had an influence on the FAS on each test week. Subsequently, a subject's FAS could potentially have increased without a concurrent increase in the quality of the movement of a task.

Plotting the FAS against the proportion of subjects achieving a task would allow the relationship between these variables to be investigated and a regression equation determined. However, as data was only available for 7 test weeks, there were an insufficient number of data points to allow the use of this methodology. Hence, to assess the influence of the subjects ability or inability to perform standing, rising to stand and sitting down, the pattern of change in the proportion of the control group and practice group subjects achieving these tasks was compared with pattern of change in the median FAS for each group on each of the test weeks. Figure 17.5 and Figure 17.6 illustrate the changes in the proportion of subjects achieving the tasks on each test week (plotted on the secondary y-axis) with the median FAS on each test week (plotted on the primary y-axis).

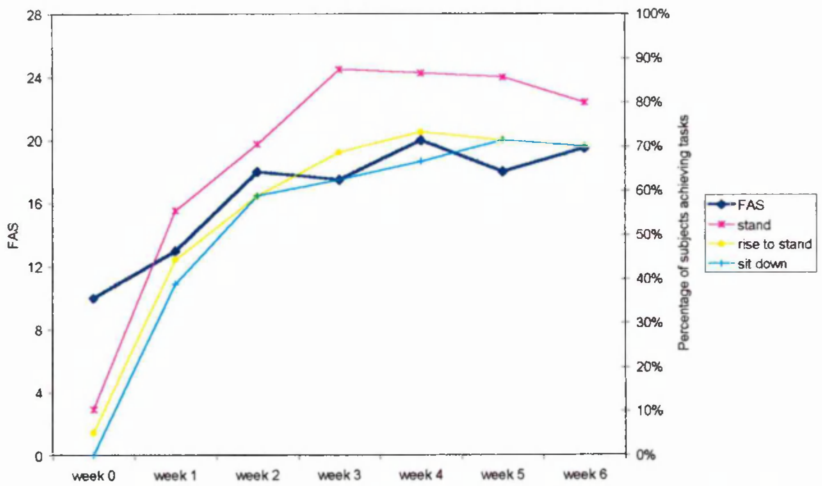


Figure 17.5 Median FAS and percentage of subjects achieving standing, rising to stand and sitting down over the test weeks. Control group.

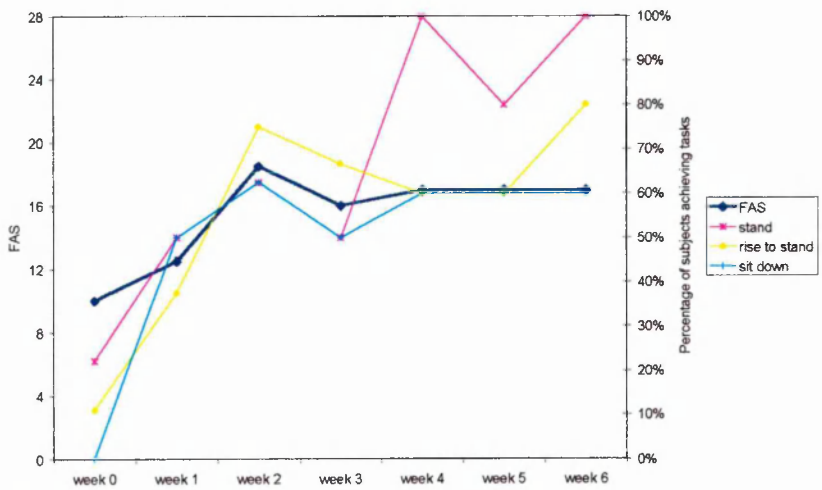


Figure 17.6 Median FAS and percentage of subjects achieving standing, rising to stand and sitting down over the test weeks. Practice group.

Figure 17.5 illustrates that the pattern of change of the median FAS for the control group over the test weeks was remarkably similar to the pattern of the changes in the proportion of control group subjects able to perform standing, rising to stand and sitting down over the test weeks. Figure 17.6 illustrates that the pattern of change of the median FAS for the practice group over the test weeks was remarkably similar to the pattern of changes in the proportion of practice group subjects able to perform rising to stand and sitting down. The pattern of changes in the proportion of practice group subjects able to stand was very similar to the pattern of changes in the median FAS for the practice group during test weeks 0-3. During test weeks 4-6 the proportion of practice group subjects able to perform standing changed while there was no change in the median FAS. However, during test weeks 4-6 the total number of subjects in the practice group was 5. This very low number of subjects meant that very small changes in the number of subjects able to perform standing resulted in a relatively large change in the proportion of subjects.

The strong similarity in the changes in the FAS and the changes in the proportion of subjects achieving standing, rising to stand and sitting down indicate that the FAS was directly influenced by the ability of the subjects to achieve these tasks. The changes in the proportion of subjects able to perform the different tasks appear to provide an explanation for the changes in the FAS.

17.2.4 Functional ability score and outcome

The baseline (week 0) total FAS had a small interquartile and 90% range for both control and practice group subjects. The median and percentiles for FAS of the control and practice group subjects during the initial measurement were similar. Improvement in ability over the test weeks was demonstrated by an increase in the FAS. The change in the FAS for the control and practice group subjects relative to the baseline score was used to determine outcome. A score which remained between the 5th and 95th percentile of the combined control and practice group baseline (week 0) measure was defined as a "fair" outcome. A "fair" outcome indicated that there had been no large improvement or deterioration in ability. A score falling below the 5th percentile was defined as a "poor" outcome and a score above the 95th percentile was defined as a "good" outcome. Subjects with a "poor" outcome had a FAS that was lower than the 90% range of the baseline measure, and subjects with a "good" outcome had a FAS that was higher than the 90% range of the baseline measure. The 5th percentile for the control and practice group subjects combined was 8.4; and the 95th percentile was 13.7. Hence any score below 8.4 during the subsequent weeks was defined as a poor outcome; and any score above 13.7 was defined as a good outcome; and any score remaining within the 90% range from the baseline measure was defined a fair outcome. Table 17.9, Figure 17.7 and Figure 17.8 display the proportion of control and practice group subjects with poor, fair and good outcome for the FAS on each test week.

		week 1	week 2	week 3	week 4	week 5	week 6
Control	Poor	11%	6%	6%	0%	0%	0%
	Fair	39%	35%	19%	40%	36%	40%
	Good	50%	59%	75%	60%	64%	60%
practice	Poor	25%	0%	17%	0%	0%	0%
	Fair	25%	25%	17%	40%	40%	40%
	Good	50%	75%	67%	60%	60%	60%

Table 17.9 Percentage of control and practice group subjects poor, fair and good outcome as compared to the baseline FAS over the test weeks.

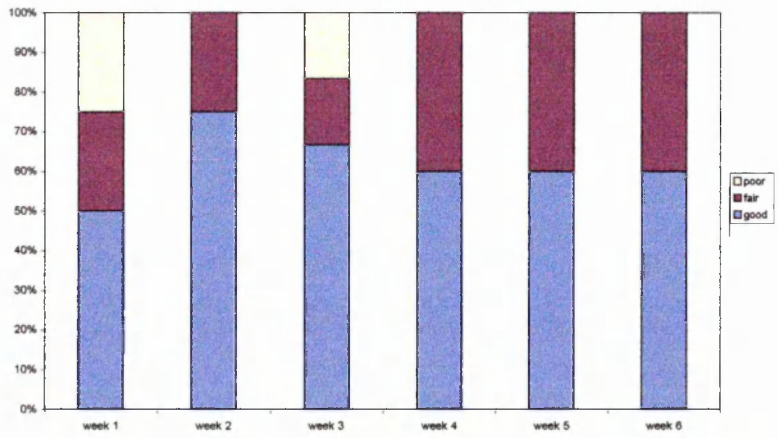


Figure 17.7 Proportion of control group subjects with poor, fair and good outcome on different test weeks.

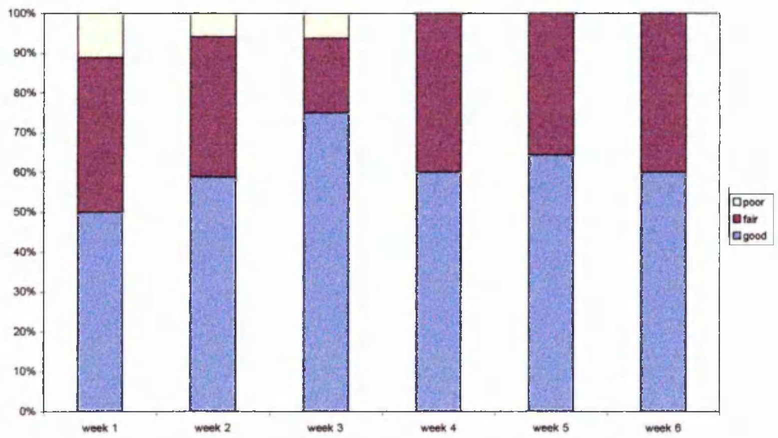


Figure 17.8 Proportion of practice group subjects with poor, fair and good outcome on different test weeks.

The proportion of subjects with good outcome on each of the test weeks remained between 50% and 75% for both the control and practice group. The proportion with poor outcome was low, and remained as 0% for both groups during weeks 3 – 6. The outcome of both groups of subjects improved between week 0 and 1. The outcome of the control group subjects also improved during week 2. However during the subsequent test weeks there was no observable pattern or trend in the results, with little change in the proportion of subjects with fair and good outcomes.

17.3 Functional ability and independent variables

The functional ability score (FAS) depicted the total functional ability of subjects, with reference to the symmetry and time variables during sitting, standing, rising to stand, sitting down, reaching to the same side and reaching across to the opposite side. The FAS was explored with reference to the subject group and to the test week. However, there were a number of independent variables that could potentially be associated with the FAS from the individual subjects.

17.3.1 Functional ability score and Barthel Index

In order to investigate the relationship between the FAS and the Barthel Index Spearman's rho was calculated. The FAS and Barthel Index values from each subject on each test week were included in the testing. The inclusion of subjects regardless of group and test weeks allowed the exploration of any association, regardless of the type of treatment or stage in rehabilitation. Spearman's rho indicated that there was a correlation of 0.519 (significance level 0.01). The relationship and regression line are displayed in Figure 17.9. This demonstrated that there was a positive association between the Barthel Index and the FAS. However, using the classification of strength of association proposed by Currier (1990), the association between the FAS and Barthel Index was described as "poor".

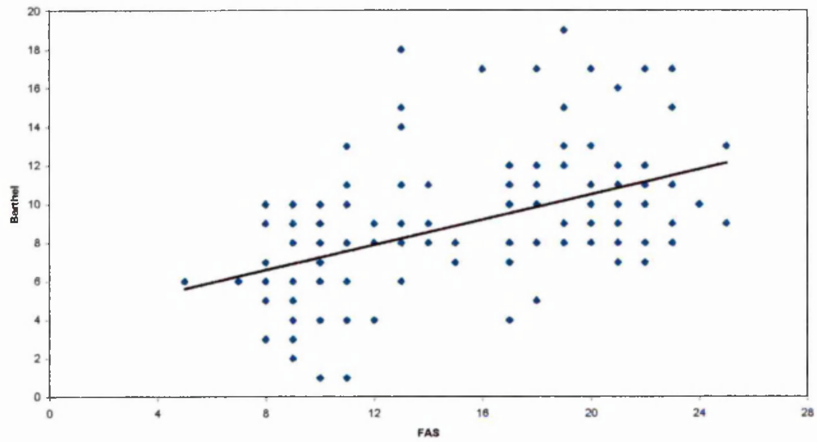


Figure 17.9 FAS against Barthel Index. All hemiplegic subjects on all test weeks.

17.3.2 Functional ability score and side of hemiplegia

The effect of the side of hemiplegia on the FAS was explored by examining the median and percentile values from the left and right hemiplegic subjects over the test weeks. Figure 17.10 illustrates the medians, interquartile ranges and ranges of the FAS for the left and right hemiplegics subjects. Table 17.10 displays the values of the medians and interquartile ranges of the left and right hemiplegic subjects.

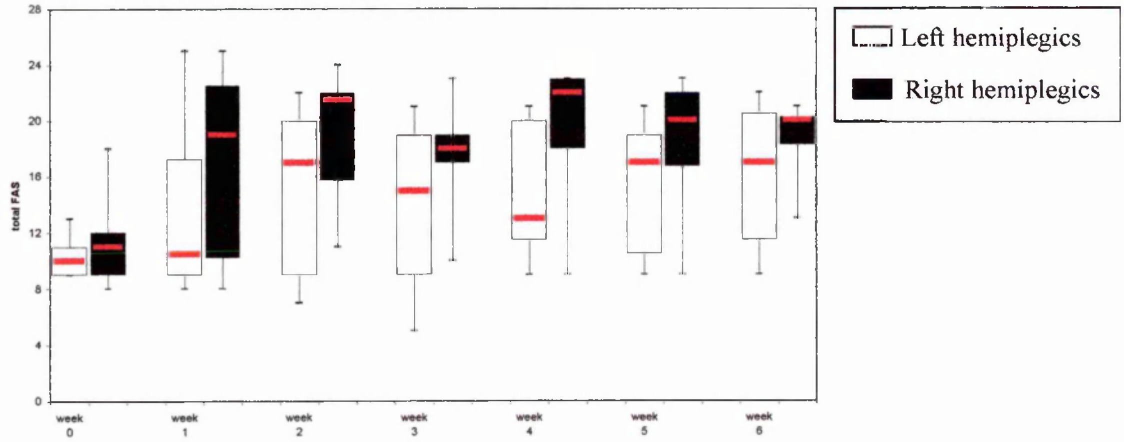


Figure 17.10 Medians, interquartile ranges and ranges of FAS for left and right hemiplegic subjects over the test weeks.

	Side of hemiplegia	week 0	week 1	week 2	week 3	week 4	week 5	week 6
median	Left	10	10.5	17	15	13	17	17
	Right	11	19	21.5	18	22	20	20
Interquartile range	Left	2	8.25	11	10	8.5	8.5	9
	Right	3	12.25	6.25	2	5	5.25	2

Table 17.10 Median and interquartile range for total FAS for hemiplegic subjects according to side of hemiplegia.

Differences can be observed between the data from the left and the right hemiplegic subjects. The median value of the left hemiplegic subjects changed little between week 0 and 1, and increased substantially between weeks 1 and 2. During weeks 2-6 there was no apparent trend in the pattern of the results pertaining to the subjects with left hemiplegia. In contrast, although the median value for the right hemiplegics was close to that of the left hemiplegics during week 0, the median value for the right hemiplegics increased substantially between week 0 and 1. Following this increase in the median FAS there was little change during the subsequent weeks. The median FAS for the right hemiplegics was higher than that for the left hemiplegics during all test weeks. During test weeks 2 – 6 the interquartile range from the right hemiplegics was notable smaller than that of the left hemiplegics; although the total range of values for the right hemiplegics remains similar to that of the left hemiplegics.

Using the definitions of poor, fair and good outcome stated earlier (section 17.2.4), the outcome of the subjects with left and right hemiplegics was determined relative to the baseline FAS. The proportion of left and right hemiplegic subjects with poor, fair and good outcome are provided in Table 17.11, and are shown graphically in Figure 17.11 and Figure 17.12.

		week 1	week 2	week 3	week 4	week 5	week 6
left	Poor	13%	7%	15%	0%	0%	0%
	Fair	50%	40%	23%	55%	45%	45%
	Good	38%	53%	62%	45%	55%	55%
right	Poor	20%	0%	0%	0%	0%	0%
	Fair	10%	20%	11%	22%	25%	25%
	Good	70%	80%	89%	78%	75%	75%

Table 17.11 Percentage of left and right hemiplegics with poor, fair and good outcome as compared to the baseline FAS over the test weeks.

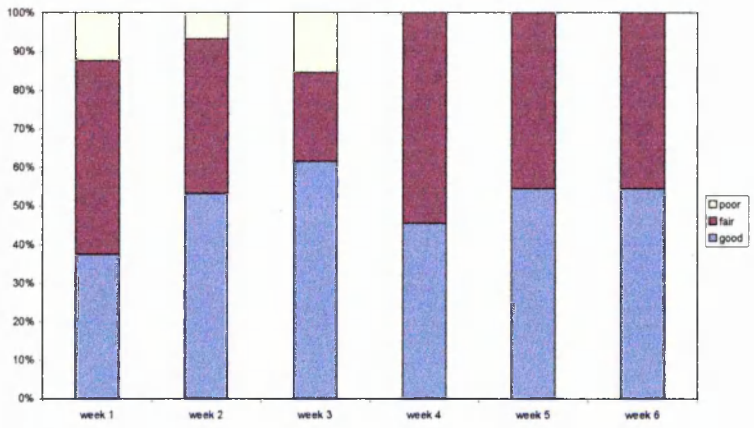


Figure 17.11 Proportion of left hemiplegic subjects with poor, fair and good outcome on different test weeks.

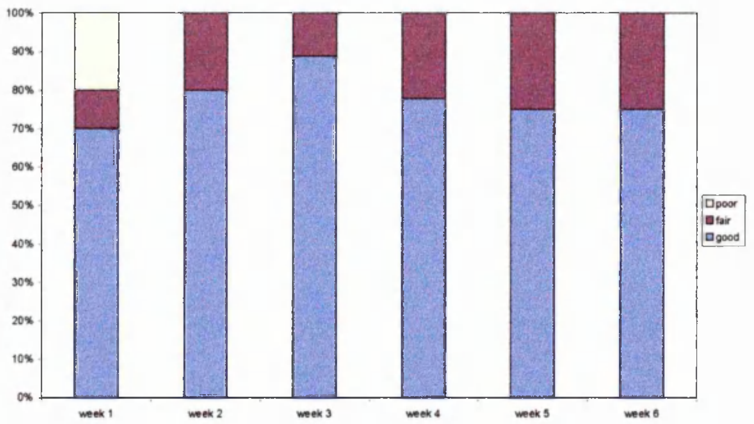


Figure 17.12 Proportion of right hemiplegic subjects with poor, fair and good outcome on different test weeks.

The data and graphs pertaining to the outcome of subjects with left and right hemiplegia demonstrates that the proportion of right hemiplegic subjects with good outcome was greater than the proportion of left hemiplegic subjects with good outcome on all test weeks. The pattern of the results over the test weeks was similar for the left and right hemiplegic subjects: for both the left and the right hemiplegic subjects the minimum proportion of subjects with good outcome occurs in week 1, and the maximum in week 3.

17.3.3 Functional ability score and stroke classification

The effect of stroke classification on the FAS was explored by examining the medians and interquartile ranges of groups of subjects classified as TACI, PACI, LACI, POCI or PICH. The medians and interquartile ranges for subjects with different stroke classifications are shown in Table 17.12.

	Stroke classification	week 0	week 1	week 2	week 3	week 4	week 5	week 6
median	TACI	11	19.5	20	18	22	18	20
	PACI	9	10.5	15	10	10	9.5	13
	LACI	10	16	20	17.5	20	21	20
	POCI	10	9	10	17	16.5	16.5	22
	PICH	11	14	21	12	16.5	10	10
Interquartile range	TACI	1.5	9.75	4	2	1	2	5.5
	PACI	0.75	10.5	7.75	6	3.5	3.5	2
	LACI	2	9	7	4.75	5.5	3.5	1.5
	POCI	1	0	1	3	3.5	3.5	0
	PICH	5	6.5	7.5	7	6.5	0	0

Table 17.12 Median values for total FAS for hemiplegic subjects according to stroke classification.

The low number of subjects with some of these classifications (POCI, n=2; PICH, n=3) prohibited the graphic representation of the medians, interquartile ranges and ranges for each of the groups of subjects. However, it has been identified in the literature that the functional recovery of patients with a PACI, LACI or POCI may be similar, but that of patients with a TACI may be substantially different (Smith and Baer, in press). Subsequently it was argued that it was appropriate to compare the functional ability of patients with classifications other than TACI with the functional ability of patients classified as TACIs. Hence, the medians, interquartile ranges and ranges of subjects classified as PACI, LACI, POCI or PICH were combined and plotted, and compared with the medians, interquartile ranges and ranges of subjects classified as TACI, in Figure 17.13.

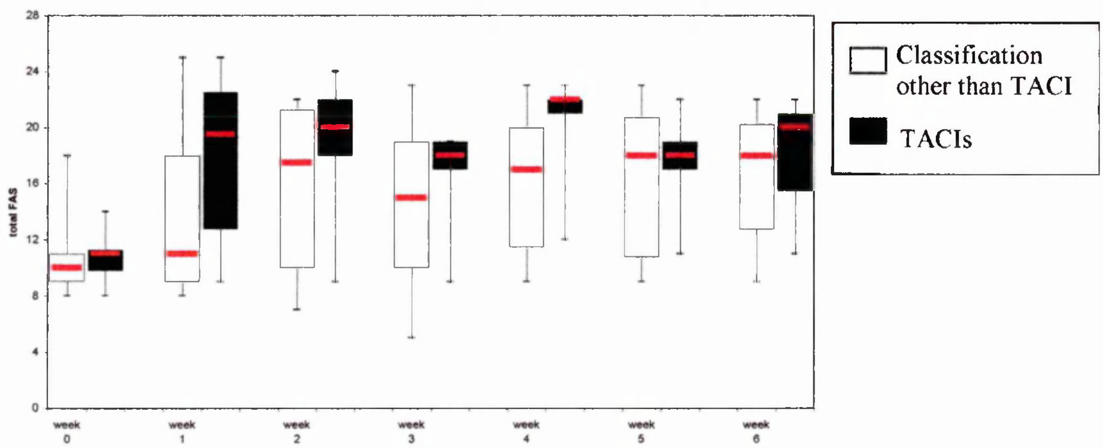


Figure 17.13 Medians, interquartile ranges and ranges of FAS for subjects classified as TACIs or with other classifications over the test weeks.

The data and graphical display suggest that the scores were similar for subjects regardless of classification at week 0. However the FAS for the subjects classified as TACI appeared to increase earlier than the FAS for subjects with other classifications. The median value of the FAS for the TACI group was greater than the median value for the combined group during weeks 0 – 4. The data for subjects with different stroke classifications indicated that the FAS for TACIs increased faster and was higher than that of PACIs throughout the test weeks. Subjects classified as LACI, POCI of PICH exhibited median functional ability scores that reached a similar magnitude as those of the TACI group, although the POCI group did not achieve this level of FAS until week 6.

As in the exploration of the change in ability of subjects with left and right hemiplegia, the outcome of the subjects with different stroke classifications relative to the baseline FAS was determined. The definitions of poor, fair and good outcome previously provided were used. Figure 17.14 - Figure 17.18 and Table 17.13 display the proportion of subjects with different classifications, with poor, fair and good outcome over the test weeks.

		week 1	week 2	week 3	week 4	week 5	week 6
TACI	**Poor**	0%	0%	0%	0%	0%	0%
	Fair	33%	20%	20%	20%	20%	33%
	Good	67%	80%	80%	80%	80%	67%
PACI	**Poor**	17%	0%	20%	0%	0%	0%
	Fair	50%	50%	40%	75%	75%	75%
	Good	33%	50%	40%	25%	25%	25%
LACI	**Poor**	33%	0%	0%	0%	0%	0%
	Fair	11%	22%	13%	29%	14%	17%
	Good	56%	78%	88%	71%	86%	83%
POCI	**Poor**	0%	0%	0%	0%	0%	0%
	Fair	100%	100%	0%	50%	50%	0%
	Good	0%	0%	100%	50%	50%	100%
PICH	**Poor**	0%	33%	50%	0%	0%	0%
	Fair	33%	0%	0%	50%	100%	100%
	Good	67%	67%	50%	50%	0%	0%

Table 17.13 Percentage of hemiplegics with different stroke classifications with poor, fair and good outcome as compared to the baseline FAS over the test weeks.

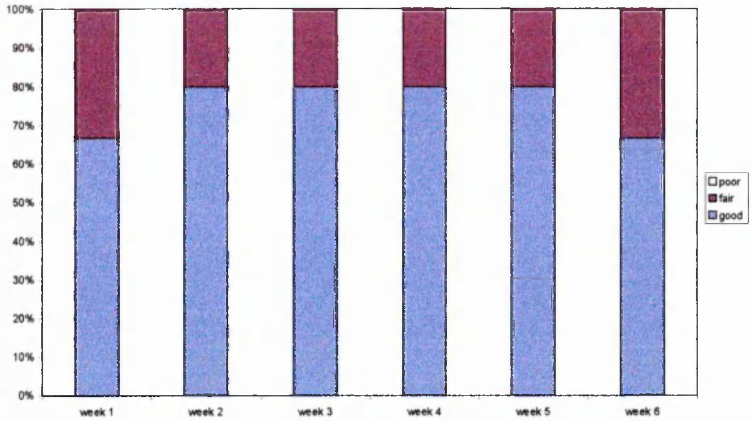


Figure 17.14 Proportion of subjects classified as TACIs with poor, fair and good outcome on different test weeks.

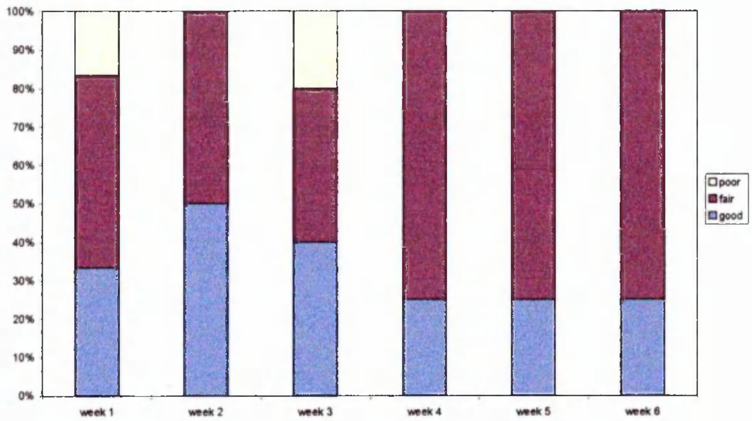


Figure 17.15 Proportion of subjects classified as PACIs with poor, fair and good outcome on different test weeks.

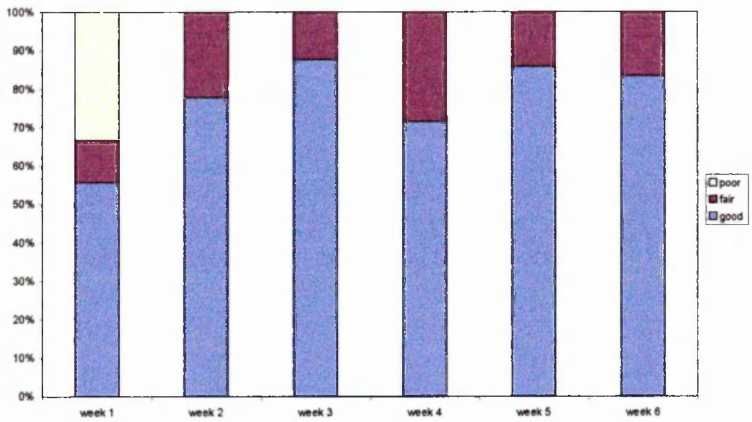


Figure 17.16 Proportion of subjects classified as LACIs with poor, fair and good outcome on different test weeks.

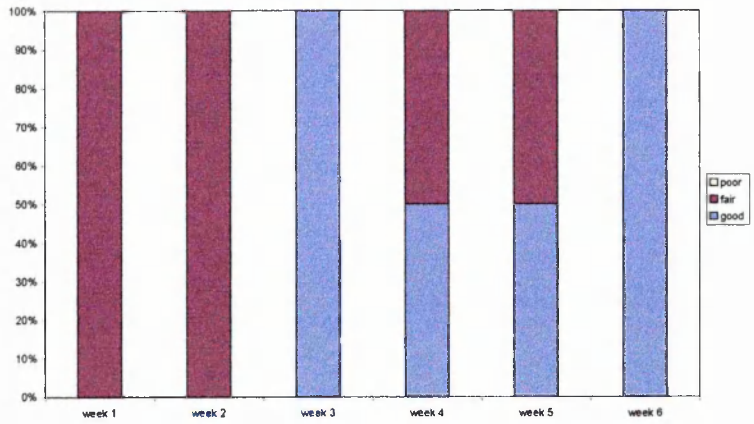


Figure 17.17 Proportion of subjects classified as POCIs with poor, fair and good outcome on different test weeks.

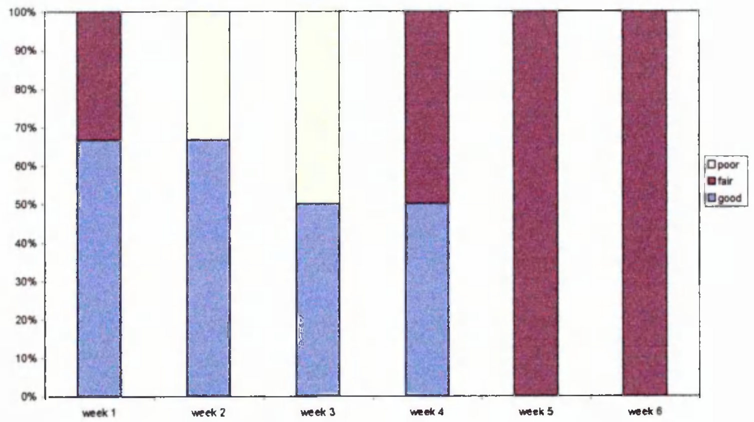


Figure 17.18 Proportion of subjects classified as PICHs with poor, fair and good outcome on different test weeks.

The proportion of subjects with TACIs with fair and good outcome over the test weeks remained relatively constant, with between 67% and 80% with good and between 20% and 33% with fair outcome on each test week. The proportion of subjects with PACIs with good outcome was less than that of subjects with TACIs: between 25% and 50% of subjects with PACI had a good outcome on each test week. The proportion of subjects with LACIs with good outcome was only 56% on week 1, but was between 71% and 88% during weeks 2 - 6. This was similar to the proportion of subjects with TACI with good outcome. The low number of subjects classified as POCI and PICH limit the ability to generalise from these results.

18. Discussion: Measurements of functional ability

18.1 Introduction

Several important issues can be explored from the results obtained from this study. Data pertaining to symmetry and time variables during a number of functional activities have been collected from healthy and hemiplegic subjects. The methods of analysis; the magnitude of the variables recorded from the healthy and hemiplegic subjects; the changes in the data collected from the hemiplegic subjects over the study weeks; and the variations in the functional ability of subjects with different independent variables have been identified and discussed, for each of the different functional tasks, in the following sections (section18.2 - 18.8).

Additionally, the following sections highlight differences that were found between the control group and practice group for each of the functional tasks. The differences between the control group and practice group have implications pertaining to the effectiveness of the regime of independent practice. Although these implications are briefly referred to within the relevant sections of this chapter, the effectiveness of the regime of practice is expounded in more detail in the following chapter (chapter 19). Likewise, while implications of the results of this study for the assessment and treatment of patients with recently acquired stroke are briefly identified at pertinent points in this chapter, issues pertaining to the clinical implications of the study results are discussed more fully in chapter 20.

18.2 Sitting

There are few reports of measurements of the symmetry of weight distribution in sitting available in the literature. It was hypothesised that this was due to the lack of suitable measurement equipment. The measurement system used in this study was accurate, precise and was suitable for the objective measurement of the symmetry of weight distribution in sitting.

18.2.1 Healthy subjects

This study demonstrated that healthy subjects had a highly symmetrical weight distribution in sitting. The variation between the healthy subjects was similar to the variation between repeated measures from individual subjects. This implies that the symmetry of weight distribution of healthy subjects varied randomly throughout the normal range. The normal range of values for the healthy subjects was low: the 5th percentile and 95th percentiles of the healthy subject symmetry indices indicated that 90% of the subjects distributed a maximum of approximately 55% (SI=-0.10) and (SI=0.06) of body weight to the right and left sides respectively. This indicates that the maximum weight distributed to one side in sitting by the healthy subjects was approximately 55%: the minimum weight distributed to one side during sitting was therefore 45%. The difference in weight distribution between the left and right sides was hence approximately 10%. Thus these results suggest that 90% of healthy subjects will randomly distribute between approximately 45% and 55% of body weight through the left and right sides.

Although no reports of measures of weight distribution in sitting were found in the literature, instantaneous measures of pressure distribution are reported (Drummond et al, 1982; Smith and Emans, 1992). Smith and Emans (1992) reported that the mean difference in pressure distribution between the left and right buttocks was 7.1%±5.5%. This value indicates that approximately 95% of the subjects measured had a difference in pressure distribution between the buttocks of less than 18.1% (mean + 2 standard deviations). The results from this study found that 90% of the healthy subjects had a maximum difference in weight distribution between the sides of approximately 10%. Therefore the measures of difference in pressure distribution reported by Smith and Emans (1992) were substantially greater than the measurements of weight distribution determined in this study. The reasons for the differences between the results of this study and the study by Smith and Emans (1992) are unknown. However, factors such as the sitting position, the measurement protocol, the reliability and validity of the equipment used; the use of instantaneous measures rather than measures derived from a period of time; and the use of parametric rather than non-parametric statistics could potentially contribute to the differences in the results recorded.

No significant associations were found between the symmetry of weight distribution in sitting and any independent variables. The small but apparently random differences in weight distribution observed to exist between healthy subjects provide an explanation for the lack of association with independent variables. Similarly there were no associations between the symmetry of weight distribution in sitting and the symmetry of weight distribution in standing, rising to stand, sitting down, reaching to the same side, or reaching across to the opposite side. Again the small but apparently random differences in weight distribution in sitting preclude the existence of any relationship between the symmetry of weight distribution in sitting and any other variables.

18.2.2 Hemiplegic subjects

This study provided the first known report of objective measures of the symmetry of weight distribution during sitting in subjects with recently acquired stroke. Measurements taken within 3 days of a subject with acute hemiplegia achieving the goal of 1 minute of sitting balance provided a valuable baseline pertaining to the sitting ability of subjects with recently acquired stroke. These measurements indicated that the weight distribution in sitting in acute stroke patients was, on average, symmetrical. The median value of the symmetry index for the hemiplegic subjects (SI=-0.01) during this initial measurement was the same as the median symmetry index for the healthy subjects (SI=-0.01). The 90% range for the hemiplegic subjects during the initial measure was 0.34. Assuming that on average the subjects had symmetrical weight distribution, this implies that 90% of the hemiplegic subjects had a difference in weight distribution of approximately 17% of body weight between the sides. This was substantially greater than the maximum difference of 10% in body weight between the sides for the healthy subjects.

Despite the lack of scientific evidence, it is commonly assumed that, following stroke, patients will have problems maintaining symmetrical alignment and weight distribution in sitting (Bobath, 1978, 1990; Davis, 1985, 1990; Carr and Shepherd, 1989a, 1992; Ashburn, 1997). The results of this study confirm that subjects with acute hemiplegia do demonstrate greater asymmetry of weight distribution than healthy subjects. However, on average the hemiplegic subjects did demonstrate symmetrical weight bearing and there was no preference for increased weight distribution to either the unaffected or affected side. The assumption is often made that the lack of activity in the affected side will result in an overuse of the unaffected side (Bobath, 1978, 1990; Davis, 1985, 1990), and that this will result in an asymmetrical posture with increased weight through the unaffected side. The baseline measurement from acute stroke patients recorded in this study does not support this assumption.

The results of the measurements taken in weeks 1, 2 and 3 remained very similar to the baseline measurement for both the control group and practice group. In weeks 4, 5 and 6 there was a very slight change in the results with the distribution shifting toward the unaffected side. During these weeks 90% of the control group subjects took a maximum weight of 53% (SI=-0.06) through the affected side, and a maximum of 61% (SI=0.22) through the unaffected side. The practice group subjects took a maximum of 54% (SI=-0.08) through the affected and 62% (SI=0.24) through the unaffected side. This indicates that, despite active physiotherapy treatment aimed at improving sitting balance, during the 3 weeks following the attainment of independent sitting there was no change in the symmetry of weight distribution during sitting for either the control or practice group subjects. During the initial 3 test weeks the hemiplegic subjects demonstrated weight distribution that was, on average, symmetrical but with greater variation than healthy subjects. Following these initial 3 weeks, there was a slight indication that the weight distribution became asymmetrical, with an increase in the distribution of weight to the unaffected side, for both the control and practice group.

There may have been a difference in the symmetry of weight distribution during sitting between the practice group subjects who were and who were not discharged during the study period. The symmetry of weight distribution in sitting of the practice group subjects who were not discharged did not appear to change over the test weeks, while the symmetry of weight distribution in sitting of the practice group subjects who were discharged appeared to shift toward the affected side. This could potentially imply a predictive relationship between the symmetry of weight bearing in sitting and discharge status, and potentially a beneficial effect of the practice in some of the subjects. However, the low numbers of subjects prevents conclusions being drawn from these observations.

Although firm conclusions cannot be drawn from the observation of the small changes in weight distribution, what is apparent from these results is the lack of any great change in the weight distribution of the patients. Despite 6 weeks of active physiotherapy treatment, which included techniques aimed at improving the symmetry of alignment and weight distribution during sitting, the symmetry of weight distribution in sitting demonstrated only minimal changes. This observation was confirmed by the proportion of subjects whose ability to achieve normal weight distribution in sitting changed over the weeks. Between the first and last measurement of the symmetry of weight distribution in sitting the ability of over 70% of the subjects did not change. This leads to the conclusion that the treatment given to the majority of patients aimed at improving the symmetry of weight distribution during sitting did not successfully meet these aims. This conclusion is supported by Nichols et al (1996) who reported that the symmetry of weight distribution of 12 hemiplegic subjects did not change significantly during a period of in-patient rehabilitation.

The results pertaining to the symmetry of weight distribution in sitting by patients with recently acquired stroke derived from this study challenge several assumptions that are made in the literature. It is often assumed in the literature that subjects with stroke will demonstrate asymmetrical weight distribution and that, with physiotherapy intervention, the symmetry of weight distribution will improve. This study found that following the achievement of independent sitting balance many patients with acute stroke demonstrated weight distribution that was, on average, symmetrical with no strong preference for weight bearing on either the unaffected or affected side. The lack of preference for weight bearing on either the unaffected or affected side during the initial measurements of sitting suggests that asymmetry of weight distribution may not be a problem in the early stroke patient. No change was observed in the symmetry of weight distribution in sitting over a period of 6 weeks, during which physiotherapy was administered, for patients with recently acquired stroke. These results highlight the importance of objective measurements of human posture and movement, both for the determination of problems following stroke and for the assessment of the effectiveness of treatment interventions. Further research is necessary to confirm these results, and to collect data from larger sample sizes.

18.3 Standing

18.3.1 Healthy subjects

This study found that young healthy subjects had highly symmetrical weight distribution in stance. Examining the percentiles indicates that 90% of the young subjects distributed a maximum of approximately 56.5% (SI=-0.13) and 54% (SI=0.08) of weight through the right and left legs respectively. The percentile values imply that slightly more weight was taken through the right than through the left leg. The small discrepancy was due to the magnitude of the tails of the distribution curve being slightly greater to the right side than to the left side. In contrast, the elderly healthy subjects distributed slightly more weight to the left side than to the right, with a median weight distribution of 52% (SI=0.04) on the left. Despite the apparent shift in the data, the maximum weight taken through one leg by 90% of the elderly subjects was approximately 57% (SI=0.14). This was similar to the maximum weight taken through the right leg of 56.5% (SI=-0.13) by the young subjects. This implies that the symmetry values for the elderly healthy subjects remained within the normal range, although the median value was shifted. It is proposed that the increased median weight distribution to the left leg demonstrated by the elderly subjects was due to chance, and occurred due to the relatively small sample size. It is surmised that these small shifts in the data would not occur if the data collection was repeated, or if a larger sample size was used.

Thus the maximum weight taken through one leg by 90% of the young healthy subjects was approximately 56.5%, and by 90% of the elderly healthy subjects was approximately 57%. The whole group data (young and elderly combined) suggested that 90% of the healthy subjects had differences of up to 13% (SI=-0.13) of body weight between the legs. This value was very similar to data provided in the literature: Sackley and Lincoln (1991) reported that 95% of the 403 healthy subjects measured had differences in weight distribution between the legs of less than 12% of body weight.

A weak, although not significant, association was found between the age (R^2=0.146), and age-group (R^2=0.137), of the healthy subjects and the symmetry of weight distribution. Sackley and Lincoln (1991) did report, from a study with a larger sample size (n=403) that there was an association between the magnitude of the difference in weight distribution between the legs and age (R^2=0.41). In contrast, Caldwell et al (1986) stated that there was no relationship between the difference in weight distribution between the legs and age, although the maximum difference in weight distribution for more elderly subjects was found to be greater than that for the young subjects. The ranges in the difference in weight distribution between the legs for the young and elderly subjects in this study were similar, and therefore did not indicate that there was an association between age and the difference in weight distribution between the legs during stance. However further research is necessary to confirm whether age is associated with the magnitude of the difference in weight distribution between the legs during stance.

The association observed in this study between age and symmetry of weight distribution during stance was not significant. Thus no significant associations existed between the symmetry of weight distribution in stance and the independent variables, or between the symmetry of weight distribution in stance and the symmetry of weight distribution during other functional activities. The variation between the mean symmetry of weight distribution for the groups of healthy subjects was slightly greater (SI=0.19 and SI=0.21 for young and elderly groups respectively) than the variation between repeated measures of weight distribution from individual subjects (SI=0.07 and SI=0.10 for young and elderly groups respectively). Despite the slightly larger variation between subjects than within subjects, these results do suggest that, as in the case for the symmetry of sitting, the variations between subjects may occur randomly within a normal range. The lack of association between the symmetry of weight distribution in stance and other variables infers that the symmetry of weight distribution in stance occurs randomly within the identified normal range of weight distribution. The existence of a similarity between the variation of repeated tests and the group variation is supported by measures of the movement of the COP during quiet stance that are reported in the literature (Black et al, 1982; Samson and Crowe, 1996).

The maximum range of weight distribution during stance was slightly greater than the maximum range of weight distribution during sitting (13% difference between the legs in stance and 10% difference between the sides during sitting). Standing involves maintaining the centre of mass (COM) within a smaller base of support (BOS) than sitting. Standing therefore provides greater challenges to the ability to balance than sitting (Horak, 1987; Ekdahl et al, 1989; Riach and Starkes, 1993). The results of this study therefore indicate that subjects may be able to maintain greater symmetry of weight distribution during the maintenance of more balanced postures. If the ability to maintain symmetrical weight distribution is greater in postures involving a larger BOS, this suggests that weight distribution is related to the ability to balance. However, the differences in weight distribution during sitting and standing were very small (3% of body weight) and did not therefore appear to be directly related to the size of the BOS. The results of this study thus challenge whether the symmetry of weight distribution during the maintenance of a posture is directly related to balance control.

18.3.2 Hemiplegic subjects

The analysis of data pertaining to the symmetry of weight distribution in stance by the hemiplegic subjects was limited due to the number of subjects who were unable to achieve independent stance. Very few subjects achieved a test of stance at week 0, but the numbers increased over the test weeks, with a maximum number of subjects achieving stance during test week 4. Despite the low numbers, the results revealed that the hemiplegic subjects who were able to stand demonstrated an increased preference for weight bearing through the unaffected leg on all test weeks. With the exception of the tendency for the median symmetry index to indicate increased weight bearing on the unaffected side, no patterns or trends in the data over the test weeks or between the control and practice group could be determined. The tendency for increased weight distribution to the unaffected side is supported by many studies reported in the literature (Dickstein et al, 1984; Bohannon and Larkin, 1985; Caldwell et al, 1986; Dettmann et al, 1987; De Weerdt et al, 1989; Sackley, 1990, 1991; Wu et al, 1996).

Exploration of the data collected over the test weeks indicated that there was no remarkable change in the data over time. The number of subjects gaining the ability to stand independently increased rapidly over the first 3 weeks. This increase in the ability to stand accounted for the increase in the proportion of subjects able to stand with abnormal or normal weight distribution over these weeks. Approximately 30%

of the control group and practice group subjects were initially unable to stand, but were able to stand with "abnormal" weight distribution at the final measurement; and approximately the same proportion were initially unable, but able with "normal" weight distribution at the final measurement. Despite the increase in the number of subjects able to stand independently over the test weeks, there was little observable change in the proportion of patients able to stand with normal symmetry of weight distribution. The patients who achieved independent stance received active physiotherapy aimed at improving their ability to achieve a normal alignment and weight distribution in stance. Despite this active physiotherapy input little change in the symmetry of the weight distribution was observed in this subject group. This finding challenges the assumption that the symmetry of weight distribution in stance will improve with physiotherapy treatment for patients with acute hemiplegia.

A further point of note is the magnitude of the range of the symmetry of weight distribution between the hemiplegic subjects during stance. Over all the test weeks for all the hemiplegic subjects 90% of the subjects distributed a maximum of approximately 32% (SI=-0.32) more weight through their affected than through their unaffected leg. 90% of the subjects distributed a maximum of approximately 45% (SI=0.45) more weight through the unaffected than through their affected leg. This implies that the maximum weight taken through the affected leg during stance was approximately 66% and the minimum through the unaffected leg was therefore 34%. Likewise, the maximum weight taken through the unaffected leg was approximately 72.5% and the minimum through the affected leg hence 27.5%. Although these figures confirmed that greater asymmetry of weight bearing occurred when more weight was taken through the unaffected leg than through the affected leg, the data also demonstrated that the asymmetry could occur in the opposite direction.

The maximum weight distributed on one leg by the healthy subjects was approximately 56.5%: less than the maximum of 66% distributed through the affected leg of hemiplegic subjects. This indicates that subjects with hemiplegia demonstrated increased weight bearing on the affected, as well as on the unaffected leg. Dettmann et al (1987) found the mean body weight distributed to the affected leg by hemiplegic subjects to be 36.1±14.6%. This implies that 95% of the hemiplegic subjects distributed a maximum of 65.3% and a minimum of 6.9% of body weight on the affected side. While the values reported by Dettmann et al (1987) indicate a maximum distribution of weight to the affected side that was very similar in magnitude to the values found in this study, the minimum weight through the affected leg reported by Dettmann et al (1987) was less than that found in this study. However, these results indicated a similar trend in weight distribution to that found in this study: the difference in the lower magnitude can be attributed to variations in the profile of the subjects and the measurement protocol. Studies reporting the increased weight distribution recorded through the unaffected leg have often failed to highlight that the asymmetry of weight distribution in subjects with hemiplegia was not unidirectional. The existence of increased weight distribution on the affected leg during stance challenges assumptions relating to the overuse of the unaffected side of the body (Bobath, 1978, 1990; Davis, 1985, 1990). Further research is required to investigate the nature of asymmetry of weight distribution in stance, and whether there are any associations between factors relating to the stroke and outcome and the preferred side of weight bearing.

18.4 Rising to stand

18.4.1 Analysis of movement

The start and end of rising to stand were determined by calculating the point where the total vertical force varied from the quiet sitting or quiet standing vertical force by more than 2 standard deviations. Although this definition of the start and end of movement has not been used by previous authors, a similar methodology in which the start and end are related to variations in the momentum of body parts has been reported (Pai and Lee, 1994; Pai et al, 1994a). In order to calculate momentum data pertaining to mass and velocity is required. This study measured vertical force data only, thus preventing the use of definitions using kinematic data. The majority of studies that have recorded force data use subjective methods for determining the start and / or end of the movement. The use of subjective methods limits the accuracy and reproducibility of the results. Durward (1994) determined the start of movement as occurring at the point of seat-off, as this point could be determined objectively, using a seat-switch. However, Durward (1994) acknowledged that restricting the analysis of the rising to stand data to only the seat-off phase was a limitation of this study.

Gioftsos and Grieve (1996) recorded force data only, and objectively identified the start and end of the movement by identifying when the total vertical force changed relative to the total vertical force during quiet sitting or quiet standing. Gioftsos and Grieve (1996) defined the start and end of the movement as occurring when the total vertical force changed by a specified percentage of body weight. The use of the stipulated percentage of body weight was not justified. Rather than using a change in percentage of the total vertical force, for which the validity of the specified magnitude remained unknown, it was more appropriate to identify when the total vertical force varied by plus or minus 2 standard deviations. The determination of two standard deviations from the mean can be justified statistically, and was related to the equations used with the kinematic data in other studies (Pai and Lee, 1994; Pai et al, 1994a).

For the purpose of this study, rising to stand was divided into a seat-on and a seat-off phase. The division into these phases was simple and highly reproducible, as the point of seat-off could be easily and reliably determined from the magnitude of the forces passing through the seat. The division of the movement of rising to stand into a seat-on and a seat-off phase is appropriate for a number of reasons. The seat-on phase and seat-off phase are distinguished by the difference in the magnitude of the BOS (Hanke et al, 1995). Balance has been identified to be directly related to the size of the BOS (Riach and Starkes, 1993) and, during rising to stand, to the size of the COM/BOS separation (Riley et al, 1991; Carr, 1992; Schultz et al, 1992). Division of the movement of rising to stand into a seat-on and seat-off phase therefore divided the movement relative to the degree of balance control required. Additionally, it has been identified that rising to stand involves a horizontal (forward flexion) and a vertical (extension) phase (Kelley et al, 1976; Pai and Rogers, 1990; Riley et al, 1990; Schenkman et al, 1990; Roebroeck et al, 1994; Hanke et al, 1995). Studies dividing rising to stand into horizontal and vertical phases have used a number of different and complex methodologies to identify the start and end of the phases. The point of seat-off has been demonstrated to occur during the transition from the horizontal phase to the vertical phase (Pai and Rogers, 1990; Schenkman et al, 1990; Riley et al, 1991; Kerr et al, 1994b). Thus, the use of seat-off can broadly divide the movement into a horizontal (seat-on) and vertical (seat-off) phase. Although, in this study seat-off was determined using measures of vertical force passing through the seat of the chair, it has been demonstrated that seat-off can be easily and accurately determined using a seat switch (Durward, 1994). The use of seat-off to divide the movement into phases is therefore a methodology that could easily be repeated in other clinical studies, regardless of the method of assessing rising to stand. Several other studies have used a force plate within the seat of the chair to objectively determine the point of seat-off (Pai and Rogers, 1990, 1991a,b; Pai and Lee, 1994; Pai et al, 1994; Hanke et al, 1995). It was identified from the literature that standardised methods of determining the start and end of movement, and for dividing the movement into phases, are essential. It is proposed that the use of seat-off is an appropriate, reliable, and easily determined point and should be used by future studies in an attempt to create standardised methodologies.

18.4.2 Healthy subjects

The symmetry of weight distribution during the seat-on phase was similar for the young and elderly healthy subjects, in this study. The healthy subjects had highly symmetrical weight distribution, with 90% of the healthy subjects distributing a maximum of 54% (SI=-0.08) and 53% (SI=0.06) of weight to the right and left sides respectively. This implies that the maximum difference between the legs was less than 8% of body weight, which was slightly less than the maximum difference of 10% found for quiet sitting. This similarity suggests that subjects maintained highly symmetrical weight distribution both during the maintenance of a quiet sitting posture and during dynamic movement within the sitting posture. Although there are measures of symmetry of weight distribution during rising to stand reported in the literature, none of the studies found reported measurements during the seat-on phase, precluding the comparison of values from this study with values in the literature.

The weight distribution during the seat-off phase of rising to stand was also found to be highly symmetrical and similar for the young and elderly subjects. However, the variation in the weight distribution during the seat-off phase was greater than that of the weight distribution during the seat-on phase. While the maximum difference in weight distribution for 90% of the healthy subjects was approximately 8% during the seat-on phase, it was approximately 12% (5th percentile, SI=-0.12; 95th percentile, SI=0.12) during the seat-off phase. Thus, while approximately between 46% and 54% of body weight was distributed to either side during the seat-on phase; this increased to approximately between 44% and 56% during the seat-off phase. The range of weight distribution determined during the seat-off phase of rising to stand was similar to that determined during quiet stance (43.5% to 56.5%). This implies that the weight distribution achieved during the maintenance of quiet stance was similar to that achieved during movement within a standing posture. This concurs with the conclusion that the weight distribution was similar in quiet sitting and during movement within a sitting posture.

The range of weight distribution determined during the seat-off phase, within which the symmetry of weight distribution of 90% of the healthy subjects fell (44%-56%), was slightly less than the range determined by the mean and standard deviations of the weight distribution during this phase of rising to stand reported by Durward (1994). Durward (1994) reported that the weight distribution during this phase of rising to stand for healthy subjects was 49.2%±4.5% implying that 95% of the sample had between 40.2% and 58.2% of body weight distributed to either side. There were no apparent reasons for the slightly greater differences in the range of weight distribution found during the study by Durward (1994). However the differences are small, and the range reported by Durward included 95% of the sample as compared to the 90% reported in this study. It is therefore proposed that the small differences in the normal range of weight distribution to either side found in these studies were random differences occurring as a result of the different statistical methods used and the smaller sample size used in this study. The relatively small magnitude of the asymmetry of weight distribution to either side during the seat-on and seat-off phases of rising to stand supports the frequently made assumption that weight distribution is symmetrical during rising to stand (Baer and Ashburn, 1995).

During the seat-on phase there is a large BOS and the COM remains within the BOS at all times. Thus, although movement was occurring in the seat-on phase and not during quiet sitting, the challenges to balance could be argued to be similar in both situations. The similarity in the challenges to balance during sitting and movement in sitting provide a potential explanation for the similarity in the difference in weight distribution during quiet sitting and during the seat-on phase of rising to stand found in this study.

During quiet stance the COM remains close to the centre of the small BOS (Murray et al, 1975). In contrast, during the seat-off phase the COM has to be accelerated forward either from out of the BOS or from the limits of the BOS, and then decelerated to remain near the centre of the BOS, creating a greater challenge to balance (Riley et al, 1991; Carr, 1992; Shultz et al, 1992). The differences in the challenges to balance during standing and the seat-off phase of rising to stand lead to the prediction that weight distribution would be less symmetrical during the seat-off phase of rising to stand than during standing. However, the results of this study found little difference in the weight distribution between quiet stance and the seat-off phase of rising to stand. This lack of difference may be due to the degree of control exerted over balance and weight distribution during the seat-off phase of rising to stand. However, this study was limited to the investigation of the mean symmetry index during rising to stand. It would therefore have been possible that, although subjects demonstrated weight distribution which was, on average, symmetrical, the variation in the weight distribution over time during the seat-off phase of rising to stand may have been greater than the variation in weight distribution over time during quiet stance. Further exploration of the data is necessary to address these questions.

The time taken to rise to stand by the healthy subjects was approximately 2.3 seconds. The range in the time taken to rise to stand was relatively high, with 90% of the subjects taking between 1.68 and 3.06 seconds. This time was considerably greater than the 0.98 seconds reported by Durward (1994). However, the time reported by Durward (1994) was determined for the seat-off phase only, and was calculated using a subjective observation of the end of movement. The time taken to rise to stand determined in this study was also longer than the weighted time derived from the literature by Durward (1994) of 1.8 seconds, and longer than the values of 1.31±0.11 seconds and 1.40±0.15 seconds reported by Mourey et al (1998). However, the large variations in the determination of the start and end of the movement used in different studies prevent any conclusions being drawn from these time differences. Despite the degree of variation in the time taken by the healthy subjects, it is proposed that the use of standardised and repeatable methods for determining the start and end of rising to stand will have produced results that are reproducible. The times reported in this study are hence presented as a valid reflection of the time taken to rise to stand.

No significant associations were determined between the symmetry or time variables recorded during rising to stand and either independent variables or symmetry or time variables from other functions. For each of the reported variables the variation between the subjects was found to be similar to the variation between repeated measures, suggesting that the weight distribution and time taken during rising to stand varied randomly within the ranges of values provided. Random variation within the normal range of results for each of the healthy subjects provides an explanation for the lack of association with independent or dependent variables.

18.4.3 Hemiplegic subjects

As in the measurement of standing, analysis of the data relating to rising to stand was limited due to the number of subjects who were unable to rise to stand independently during the study period. The weight distribution of the practice group subjects was fairly symmetrical during the seat-on phase throughout the test weeks. The greatest median symmetry index on any of the test weeks for the practice group subjects (SI=0.06) indicated that the subjects distributed 53% of body weight to the unaffected side and 47% to the affected side. The percentile values also demonstrate that the weight distribution was approximately symmetrical. 90% of the practice group subjects distributed a maximum of 57.5% of weight to the affected side and minimum of 42.5% to the unaffected side (SI=-0.15); and a maximum of 57% to the unaffected side and a minimum of 43% to the affected side (SI=0.14) throughout the test period. This implies that the practice group subjects had a maximum difference in weight distribution between the sides of approximately 15%, with the average weight distribution being symmetrical. While a maximum difference between the sides of 15% indicates greater asymmetry than the healthy subjects, who demonstrated a maximum difference in weight distribution of approximately 8%, this value was comparable with the maximum difference in weight distribution during quiet sitting of approximately 17% by the stroke patients. The practice group subjects therefore demonstrated a similar pattern to the healthy subjects, with a maximum difference in weight bearing that was similar both during quiet sitting and during the seat-on phase of rising to stand. This similarity supports the suggestion that balance during the maintenance of a posture and during movement within that posture may be related.

In contrast to the practice group subjects, the control group demonstrated asymmetry of weight bearing during the seat-on phase, with increased weight distribution to the unaffected side during weeks 1-6. During these weeks the maximum weight taken through the affected side by 90% of the control group subjects was 55.5% (SI=-0.11), and the maximum weight taken through the unaffected side was 75.5% (SI=0.51). Thus, in comparison to the maximum difference between the sides of 15% by the practice group, the maximum difference between the sides was approximately 51% for the control group with a notable preference for weight bearing through the unaffected side. Despite these observable differences between the symmetry indices of the control group and practice group there were no significant difference between the ability of the two groups to achieve normal or abnormal weight distribution during this phase. It is suggested that the large variation between the difference in weight bearing between the sides was due to a small number of outliers within the control group. This suggestion was supported by the relatively large range and 90% range of the control group data during some test weeks.

Although the data for the symmetry of weight distribution during the seat-on phase did indicate an increased preference for weight bearing through the unaffected side by the control group, the magnitude of the differences between the control and practice group were small. Additionally there was a large overlap between the range of values for the control group and practice group. Thus the results of this study do not support the existence of a difference between the control and practice group in the symmetry of weight distribution during rising to stand. Although the control group tended to demonstrate increased weight bearing to the unaffected side, the degree of asymmetry was generally small. It was concluded that during the seat-on phase of rising to stand the hemiplegic subjects tended to demonstrate weight distribution that was, on average, symmetrical although there was a greater variation between the hemiplegic subjects than between the healthy subjects.

During the seat-off phase, the maximum weight distributed by 90% of the control group subjects on any of the test weeks through the affected leg was approximately

59% (SI=-0.18), and through the unaffected leg was approximately 86% (SI=0.72). The values for the practice group were similar, being 59% (SI=-0.18) and 87.5% (SI=0.75) respectively. These values demonstrate that there was a preference for increased weight distribution through the unaffected leg during the seat-off phase by both the control and practice group subjects. This trend occurred throughout the test weeks, and there were no notable differences between the symmetry of weight distribution for the control and practice group subjects. The data indicate that the hemiplegic subjects did not tend to take much more than a normal proportion of weight through the affected leg (the healthy subjects took a maximum of approximately 56% of weight through one leg during this phase). In contrast, the maximum amount of weight that was distributed through the unaffected leg was substantially greater than the normal levels indicated by healthy subject data.

The differences between the weight borne through the affected and unaffected leg indicate that the hemiplegic subjects not only had an increased tendency to weight bear through their unaffected limb, but also had a tendency to distribute a substantially greater proportion of weight through the unaffected side. Durward (1994) reported that hemiplegic subjects distributed an average of 37.5% of body weight to the affected leg and 62.5% to the unaffected leg during what is equivalent to the seat-off phase of rising to stand. The median symmetry index determined in this study varied over the test weeks. During weeks 1-6, the greatest median value for the control group indicated that the control group subjects distributed 41.5% of body weight on the affected leg and 58.5% of body weight on the unaffected leg. For the practice group the greatest median value over test weeks 1-6 indicated that the practice group subjects distributed 36.5% of body weight to the affected side and 63.5% of body weight to the unaffected side. The values determined in this study are supported by the values reported by Durward (1994), demonstrating a tendency for increased weight bearing on the unaffected side.

The weight distribution of the healthy subjects was similar during quiet sitting and during the seat-on phase of rising to stand, and was similar during quiet stance and during the seat-off phase of rising to stand. It has been demonstrated that for the practice group subjects the difference in weight distribution between the sides was similar during quiet sitting and during the seat-on phase of rising to stand. However, this pattern did not occur between quiet sitting and the seat-on phase for the control group, or between quiet standing and the seat-off phase for the practice or control group. This difference in symmetry of weight distribution between quiet postures and movement within postures indicates that, while the control group subjects could maintain relatively symmetrical weight distribution during quiet sitting, this symmetry could not be maintained during movement within the seated posture. The difference between the symmetry during these functions leads to the suggestion that, while the control group subjects could maintain a posture, their control over the COM within the BOS during active movement was impaired. For both the control and practice group subjects the degree of asymmetry toward the unaffected side was greater during the seat-off phase of rising to stand than during quiet stance. It can be proposed that this difference was due to impairments in the ability to control the COM during the dynamic movement of the seat-off phase of rising to stand: a movement providing many challenges to balance. This refutes the proposal arising from the healthy subject data stating that balance was similar during the maintenance of a posture and during movement within a posture. Alternatively it can be suggested that the difference between the healthy and hemiplegic subjects was directly related to a lack of control in the affected leg of hemiplegic subjects, resulting in the necessity to use greater muscle force with the unaffected leg, and thus the measurement of greater vertical force through the unaffected leg. The small sample size in this study limits the ability to generalise from these results.

The ability of only 1 subject in each of the control and practice group to achieve rising to stand during test week 0 prevented analysis of the baseline measurement of the time taken to rise to stand. The median time taken to rise to stand by the control group varied from 3.98 to 5.31 seconds between weeks 1 and 6. For the practice group the median time taken was between 3.92 and 6.76 seconds for test weeks 1-5. The range of time taken was large, with 90% of the control group subjects taking between 2.11 seconds and 10.33 seconds, and 90% of the practice group subjects taking between 1.67 and 10.04 seconds during these test weeks. The median value during week 6 for the practice group was considerably larger than the median values in previous weeks, or for the control group subjects. The low number of subjects achieving rising to stand during this test week may have produced what appears to be an anomalous result.

There was little observable pattern in the times taken by control and practice group subjects over the test weeks. However, exploration of the times taken by subjects completing 4 or more test weeks and exploration of the times at each subjects' first and final measurement did indicate that the time taken to rise to stand decreased over the test period. The finding of differences between the times taken as derived from the whole group data, and those derived taking the effect of discharge into account emphasises the care which must be taken in interpreting this data in light of the effects of the discharged subjects. The suggestion that the time taken to rise to stand decreased over time was supported by the work of Durward (1994), which reported that this time decreased significantly ($p<0.05$) over a period during which rehabilitation was given.

Comparison of the time recorded in this study with values reported in the literature was hindered by the lack of standardisation of the start and end of the movement recorded. The times reported by Durward (1994) referred to only the time for the seat-off phase. As would be predicted, the times reported by Durward (1994) were lower than those determined in this study; with a mean value of 3.49±1.63s found for the first measurement. However, the differences in the definition of the movement of rising to stand and in the patient groups tested prevent further comparison of these results.

Assessing the ability of the hemiplegic subjects relative to the healthy subjects over the different test weeks and the changes between the initial and final test weeks highlighted a number of general features. While the majority of the hemiplegic subjects were unable to perform rising to stand during week 0, a relatively large proportion of the subjects gained this ability during the ensuing 6 weeks. However, the majority of both control and practice group subjects who achieved rising to stand demonstrated outcome variables that remained with out the healthy subject range throughout the test period. Although the number of subjects able to rise to stand increased during the 6 weeks of treatment, the ability of the subjects to have weight distribution and time variables in the normal range did not increase. The majority of the hemiplegic subjects who were able to rise to stand demonstrated abnormal weight distribution during the seat-on and seat-off phases and abnormal time to rise to stand. For the symmetry and time variables, for both the control and practice group, the maximum proportion of subjects with variables within the normal range was 40%, while the maximum proportion with variables with out the normal range was 80%, on any of the test weeks. The pattern of greater proportions of subjects demonstrating abnormal symmetry and time variables remained throughout the test weeks. The lack of change in the ability of hemiplegic subjects over the 6-week period was highlighted by these results. This lack of change challenges the assumption that subjects with hemiplegia can regain normal patterns of movement, and questions the ability of physiotherapy to promote normal patterns of rising to stand.

18.5 Sitting down

18.5.1 Analysis of movement

This was the first known report of a study using force data that explored both rising to stand and sitting down, and used comparable objective definitions for determining the start and end of movement and for division of the movement into phases during sitting down and during rising to stand. The need for investigation of sitting down, and for the use of standardised, clearly defined, methods for determining the start and end of the movement was emphasised by the literature. It is proposed that the definitions of the start and end of movement used in this study are valid and reliable and would allow easy reproduction in future studies. The use of the same methodology to determine the start and end of both rising to stand and sitting down was advantageous as it allowed valid comparison between the seat-on and seat-off phases of the two movements.

18.5.2 Healthy subjects

On average, the healthy subjects had symmetrical weight distribution during the seat-off and seat-on phases of sitting down. During the seat-off phase 90% of the healthy subjects distributed a maximum of 56% (SI=-0.12) and 57% (SI=0.14) of body weight to the right and left sides respectively. This implies that 90% of the healthy subjects had a difference of less than 14% between the sides during the seat-off phase. During the seat-on phase 90% of the healthy subjects distributed a maximum of 55% (5^{th} percentile, SI=-0.10; 95^{th} percentile, SI=0.10) of body weight to either side; a difference of less than 10% between the sides. The weight distribution during the seat-off phase of sitting down and rising to stand was very similar, with 90% of the healthy subjects distributing between 44% and 56% to either side during rising to stand and between 43% and 57% during sitting down. The weight distribution during the seat-on phases of sitting down and rising to stand were also very similar, with 90% of the healthy subjects distributing between 46% and 54% and between 45% and 55% body weight to either side during the seat-on phases of rising to stand and sitting down respectively.

The results from the seat-off phase of sitting down can be compared with the mean weight distribution of 48.7±4.1% reported for the descending phase by Durward (1994). This implies that 95% of the 120 healthy subjects tested had between 40.5% and 56.9% of body weight through one leg during the seat-off phase. This was a similar range to the 43% to 57%, which included 90% of the healthy subjects in this study.

The difference in weight distribution between the sides during the seat-off phase of sitting down and during quiet stance was similar, with 90% of healthy subjects having differences of up to 13% between the legs during stance, and up to 14% during the seat-off phase of sitting down. This similarity concurs with the similarity between the results for stance and for the seat-off phase of rising to stand. The differences between the weight distribution during quiet sitting and the weight distribution during the seat-on phases of rising to stand and sitting down were also similar. The similarity between the symmetry of weight distribution during maintenance of a posture and during movement within that posture challenges the assumption that asymmetry of weight distribution will be greater during activities providing greater challenges to balance. However, as has previously been discussed, the ability to draw conclusions from this study relating to the stability of a posture or movement was limited due to the use of the mean symmetry values.

The average time taken to sit down was approximately 2.9 seconds, with 90% of the healthy subjects taking between 2.2 and 3.6 seconds. This was slightly longer than the 2.04±0.4 seconds recorded by Durward (1994); relatively similar to the 2.5

seconds reported by Engardt and Olsson (1992), and substantially longer than the values (1.40±0.15s and 1.69±0.31s) reported by Mourey et al (1998). The longer time taken by subjects in this study as compared to the study by Durward (1994) was as expected, as Durward (1994) defined the end of movement as occurring at seat-on while in this study recording continued until movement (as determined by changes in vertical forces) had ceased. The similarity of the time reported by Engardt and Olsson (1992) supported the time determined in this study, while the times reported by Mourey et al (1998) were less than any other values found in the literature. The reason for the methodology adopted for determining the start and end of movement by Mourey et al (1998) was not explained and may not, therefore, be a valid representation of the start and end of the movement.

Although the magnitude of the difference between the times taken to rise to stand and sit down recorded in this study was not as large as that reported by Durward (1994), in both studies the time taken to sit down was longer than the time taken to rise to stand. It could be predicted that, as sitting down involves the movement from a small BOS to a relatively large BOS, less control is required over the movement of the COM during sitting down than during rising to stand. However the greater length of time taken to sit down implied that active control was exerted over the movement of the COM during this movement. It could be argued that the longer time taken to sit down is indicative of the degree of postural control exerted over the movement of the COM during the descent.

A significant relationship was found between the dominant hand of the healthy subjects and the symmetry of weight distribution during the seat-on phase. It could be proposed that this relationship was due to the use of the arm rests during sitting down, or due to the subjects turning around in one direction to observe the chair before sitting down. The regression equation indicated that left-handed subjects distributed more weight to the left side (symmetry index more positive), supporting the suggestion that subjects tend to place more force through the arm rest on their dominant side. There was no evidence found in the literature pertaining to the distribution of forces during turning around to look behind. There were a number of factors that limited the ability to generalise from these results. A key factor was the inequality in the distribution of subjects with left and right dominance; with 92% of the healthy subjects having a dominant right hand. A further limitation was that the symmetry variable was the mean value from throughout the seat-on phase of sitting down. Durward (1994) found that the distribution on body weight through the armrests was only approximately 1.5% of body weight during sitting down. With such small magnitudes of force it is unlikely that the use of the armrest by the dominant hand could have substantially influenced the mean symmetry result. It is proposed that the association between hand dominance and the symmetry of weight distribution during the seat-on phase was anomalous, and possibly related to the low number of subjects with dominant left hands. Further research is required to confirm or refute this association. No significant associations were found between the symmetry and time variables and the other independent variables or the variables relating to other functions. As previously, it was proposed that the explanation for the lack of association was related to random variation between and within subjects.

18.5.3 Hemiplegic subjects

During the seat-off phase of sitting down the maximum weights distributed to the affected and unaffected sides, respectively, were 51.5% (SI=-0.03) and 81.5% (SI=0.63) of body weight for 90% of the control group subjects, on any of the test weeks. For 90% of the practice group subjects, the maximum weight distributed to the affected and unaffected sides were 56.5% (SI=-0.13) and 74.5% (SI=0.49) respectively on any of the test weeks. These figures clearly demonstrate the preference for weight bearing through the unaffected side by both the control and practice group subjects throughout the test weeks. Although the median value for the symmetry of weight distribution during the seat-off phase was less for the practice group during week 6, the percentile values still demonstrated a shift in the results toward the unaffected side. The anomaly of the lower median and 25th percentile was likely to be related to the low number of subjects in the practice group measured performing sitting down during week 6. Thus there were no apparent patterns in the weight distribution during the seat-off phase, or differences between the control and practice group. The degree of asymmetry of weight distribution toward the unaffected side was similar during this phase to that during the seat-off phase of rising to stand. There were also similarities between the symmetry during the seat-off phases of rising to stand and sitting down for the healthy subjects. The similarities between these phases for both the healthy and the hemiplegic subjects suggest that the affinity between these functions result in similar challenges to postural control.

A significant positive relationship was found between the symmetry of weight distribution during quiet stance and the symmetry of weight distribution during the seat-off phase of sitting down ($R^2=0.178$, $p<0.05$). The association between these variables indicated that subjects distributing more weight to the unaffected side during stance would also distribute more weight to the unaffected side during the seat-off phase of sitting down. The relationship between these variables demonstrated that, unlike the healthy subjects whose symmetry of weight distribution during different functions occurred randomly, for the hemiplegic subjects a preference for directional weight distribution during stance corresponded with a preference for directional weight distribution during the seat-off phase of sitting down. The symmetry of weight distribution of the hemiplegic subjects did not, therefore, appear to occur randomly. If the symmetry of weight distribution did occur randomly, this would support the argument that the asymmetry of weight distribution was related to a global impairment in the ability to control the COM within the BOS. However, the distinct and repetitive preference for weight bearing through the unaffected limb leads to the argument that the asymmetry of weight distribution was related to the motor control over the affected limb during stance and during movement in stance. An increase in muscular activity by the unaffected limb could result in a related increase in vertical force through the unaffected limb during posture and movement. These suggestions have implications that are central to the rehabilitation of patients with stroke. Further research is necessary to investigate the apparent preference for weight bearing through the unaffected limb in subjects with hemiplegia.

Durward (1994) measured a mean distribution of weight on the affected leg for subjects with hemiplegia of 38.4±13.4% during the seat-off phase, implying that 95% of the subjects tested distributed between 11.6% and 65.2% of body weight to the affected side. This data was comparable with the data recorded in this study which showed a distribution to the affected side of between 18.5% (maximum on unaffected = 81.5%) and 51.5% for 90% of the control group and between 25.5% (maximum on unaffected = 74.5%) and 56.5% for 90% of the practice group. Durward's slightly greater range of values corresponds to 95% of the subjects, rather than to 90% as in this study, and may be further explained by differences in subject samples and testing protocols between the studies.

During the seat-on phase for 90% of the control group subjects, the maximum weight distributed to the affected and unaffected sides were approximately 64.5% (SI=-0.29) and 74.5% (SI=0.49) respectively during any of the test weeks. These values identify that there was a slight preference for increased weight bearing to the unaffected side; the results demonstrate that this preference was more apparent during test weeks 3-6. However, with the exception of the slight preference for increased weight distribution to the unaffected side, no remarkable trends can be observed in the distribution of weight between the sides during the seat-on phase for the control group.

The pattern of results from the seat-on phase for the practice group subjects can be observed to be different from that of the control group subjects. During test weeks 1-3 the range in the distribution of weight of the practice group subjects was less than that of the control group subjects, although the slight preference for increased weight distribution to the unaffected side was apparent. During weeks 1-3 90% of the practice group subjects had a maximum of 58% (SI = -0.16) of weight distributed to the affected side and a maximum of 66.5% (SI = 0.33) of weight distributed to the unaffected side. In contrast, during weeks 4-5, the pattern reversed with 90% of the practice group subjects demonstrating a maximum of 62.5% (SI = -0.25) of weight distributed to the affected side and a maximum of 52% (SI = 0.04) distributed to the unaffected side. This tendency for increased weight bearing to the affected side by the practice group subjects during weeks 4 and 5 did not relate to an overall pattern or trend in the results of the practice group. The low number of subjects in the practice group limits the ability to draw firm conclusions from these results. Although these differences occurred, there were no significant differences in the ability of the control and practice group to achieve normal weight distribution during this phase. It is suggested that the differences between the control and practice group were anomalous, and would not be reproducible in further studies. Further studies are required to confirm this.

The time taken to sit down by both the control and practice group subjects was very similar throughout the test period with no trend or pattern over the test weeks. The median time taken by the control and practice subjects varied from 2.82 to 4.33 seconds over the test weeks. The variation in the time taken by the hemiplegic subjects to sit down was substantially less than the variation in the time taken by the hemiplegic subjects to rise to stand. 90% of the hemiplegic subjects took between 1.76 and 6.69 seconds to sit down, in comparison to times of over 10 seconds during rising to stand. Durward (1994) reported lower times to sit down, of 1.69 – 5.69s, for 95% of subjects. However the times reported by Durward were for the seat-off phase of sitting down only.

As in the case for rising to stand, the data pertaining to the ability of the hemiplegic subjects during the test weeks provided valuable information relating to changes in the ability of the subjects over time. None of the hemiplegic subjects was able to perform sitting down during the initial measurement, which highlights the degree of impairment in acute hemiplegic subjects. The subjects who achieve the ability to sit down independently tended to have greater asymmetry of weight distribution than healthy subjects did, during both the seat-off and seat-on phases, and tended to take longer to perform the function. Approximately 30% of the subjects remained unable to sit down independently throughout the study period. Approximately 50-60% had weight distribution during the seat-off phase and time taken to sit down with out the normal range; and approximately 30-40% had weight distribution during the seat-on phase with out the normal range.

Both the impairment of the hemiplegic subjects and the failure of the ability of these subjects to improve with active treatment were highlighted by the results of this study. The lack of difference in the subjects over the test weeks, and the high proportion of subjects with "abnormal" outcome variables during their final test week challenged whether these subjects were able to regain the ability to perform sitting down with normal symmetry and time variables and whether the physiotherapy treatment was adequately addressing this impairment.

18.6 Reaching to the same side

18.6.1 Analysis of movement

No studies were found in the literature that assessed weight transference under both the seat and the feet during lateral reaching from sitting. The lack of studies pertaining to measures of symmetry during lateral reaching precluded the identification of methods of data analysis from the literature, and prevented the comparison of the results from this study with the results from other studies.

The assessment of the symmetry of weight distribution during reaching was argued to be fundamentally different from the assessment of the symmetry of weight distribution in sitting, standing, rising to stand or sitting down. Sitting, standing, rising to stand and sitting down were all classed as "symmetrical" tasks, with the left and right sides of the body having identical functions. In each of these tasks it is generally assumed that healthy subjects will execute the function with symmetrical movement and weight distribution. The results of this study confirmed that healthy subjects had symmetry weight distribution during these "symmetrical" tasks. In contrast to the "symmetrical" tasks, the goal of reaching to the side was to achieve maximum weight transference on to one side. Thus, reaching to the side actively encouraged *asymmetry* of movement and weight distribution. Although there were fundamental differences between the goals of the "symmetrical" tasks and the reaching ("asymmetrical") tasks, the symmetry index remained appropriate for both these types of functional tasks. The symmetry index provided a continuous scale, capable of identifying the degree of *asymmetry* achieved during a movement.

In order to identify appropriate measures of outcome, for the analysis of reaching to the same side, the pattern of the symmetry index during the movement was initially explored. The pattern of the symmetry index during reaching to the same side was found to be consistent between the healthy subjects and involved a smooth transference of weight over to the side being reached to, followed by a return to quiet resting symmetry index. The magnitude of the maximum asymmetry (peak symmetry index) was investigated; it was argued that this value provided a quantifiable measure of a subject's ability to transfer weight to that side. In addition, the symmetry of weight distribution following the weight transference was investigated (mean symmetry index during sitting after reaching). It was anticipated that following a movement which encouraged asymmetrical weight distribution, a subject would return to sit with symmetrical weight distribution following the movement. The time taken to complete the movement was also determined, to allow the investigation of the association of the time taken to reach with other variables.

An additional feature that can be observed from the graphs of the SI during reaching to the same side, is the apparent tendency for the SI to initially have a small change in the direction opposite to the direction being reached to. At the end of the movement the SI can again be observed to move past the point of symmetrical weight distribution in the direction opposite to the direction reached to. This observation is supported by reports in the literature that the acceleration of the arm at the beginning of a reaching movement is associated with a movement of the trunk in the opposite direction (Moore and Brunt, 1991; Moore et al, 1992). It has been proposed that this occurs as an equal and opposite arm to shoulder force following the arm acceleration (Moore and Brunt, 1991, Moore et al, 1992). However whether this occurs as a reaction or as an anticipatory postural adjustment remains unknown. Further research is required to explore the pattern of the change in the SI in the direction opposite to the reach at the beginning and end of the movement cycle.

In order to determine the time taken to reach, accurate calculation of the start and end of movement was required. Since reports of measures of reaching to the same side were not found in the literature, it was important to define methods of determining the start and end of the movement, and of calculating the desired outcome variables, which were accurate, reliable and repeatable in future studies. Reports of anticipatory postural adjustments prior to reaching (Friedli et al, 1984, 1988; Horak et al, 1984; Bouisset and Zattara, 1987) emphasise the need for objective measures of the start of movement, as subjective methods such as using the time of the command to move could provide erroneous results. Methods similar to those used to define the start and end of rising to stand and sitting down were adopted, as the use of changes in output relative to the mean and standard deviation were accepted statistical methods. However, while the start and end of rising to stand was determined through identification of change in the total vertical force, there was no evidence to suggest that the total vertical force would vary during reaching. The nature of reaching resulted in a change in the symmetry index: the changes in the symmetry index relative to the resting symmetry index were therefore used to define and derive the start and end of the movement of reaching to the same side. The high degree of similarity between the curves obtained when the data from each healthy subject was converted to exclude the influence of differences in time and velocity (by determining 100 data points for the x-axis from the range of data) and plotted on the same graph (Figure 14.4) confirmed the validity of the definitions used to determine the start and end of movement.

Further research into the analysis of weight transference during reaching is indicated, in order to confirm the observations made in this study and to verify the validity of the methodology for identifying the start and end of the movement. However, it is proposed that the methods adopted in this study provided an accurate, valid and reproducible methodology for quantifying the asymmetry of weight distribution achieved during reaching to the same side and the symmetry of weight distribution returned to following reaching to the same side.

18.6.2 Healthy subjects

The median peak symmetry index for the healthy subjects was approximately 0.85. This implied that the healthy subjects achieved a difference in weight distribution of up to 85%. This equated to approximately 92.5% of body weight being distributed through the side that was being reached to. There was relatively little variation in the maximum amount of weight that was distributed through the side reached to. 90% of the healthy subjects had peak symmetry indices of between approximately 0.70 and 0.94. This equated to peak weight distribution through the side reached to of between 85% and 97% of body weight. These values constitute the first reported measurements of the maximum amount of weight transference that can be achieved during lateral reaching from a sitting position. The measurements of the asymmetry of weight distribution achieved demonstrated that healthy subjects had the ability to control the position of the COM within the BOS during the transfer of an extremely large proportion of body weight on to one side of the body.

The distribution of the symmetry index during quiet sitting following reaching to the same side was not normal, with more weight distributed through the side reached to than through the opposite side. Although the median value showed that the weight distribution was fairly symmetrical, with 51.5% (SI=0.03) of body weight distributed to the side reached to, the increased tendency to weight bear on the side reached to was confirmed by the interquartile range, which did not include symmetrical distribution (25th percentile, SI=0.00; 75th percentile, SI=0.07). This indicated that the 50% of the subjects with symmetry indices within the central part of the distribution curve all distributed more weight on to the side reached to than the opposite side during sitting after reaching to the same side. The maximum weight distribution on the side reached to for 90% of the healthy subjects was approximately 57% (SI=0.14), while the maximum weight distribution on the side opposite that reached to was 54% (SI=-0.08). Thus, although the interquartile range indicated a shift in the data, the maximum weight distributed to either side by 90% of the healthy subjects was remarkably similar. It is therefore possible that the observed shift was due to random occurrence and the small sample size. If, however, healthy subjects did maintain increased weight bearing on the side reached to, following reaching to the same side, this would lead to the suggestion that a subject's symmetry of weight distribution could be directly influenced by active lateral weight transference. Such a suggestion would have implications for the treatment of patients, and would challenge the assumption that healthy subjects tended to return to symmetrical posture and weight distribution following movement. It is consequently important that further research is carried out to demonstrate whether the noted shift in the results is repeatable.

90% of the young healthy subjects took between approximately 5.4 and 8.8 seconds to complete reaching to the same side, and 90% of the elderly subjects took between approximately 5.6 and 11.5 seconds to complete the movement. As can be seen from these figures, the lower end of the range of time taken was similar for the young and elderly subjects, while the upper end was different, with elderly subjects taking longer than young subjects to complete the movement. The difference in the upper time limit suggests that the distribution curve of the time variables for either the young or elderly subjects, or both, was not normal. Observation of the distribution curves confirmed that there were distinct differences between the curves for the young and elderly subjects, with neither of the curves exhibiting normal distribution. Statistical tests further confirmed the differences in the time taken by the young and elderly subjects, which showed significant positive association between age and time taken to reach to the same side. Since there were no further associations with independent variables, such as height or mass, it was concluded that the differences observed between the time taken by subjects of different age groups was directly related to age and not to a secondary factor.

A number of different arguments can be posed to explain the longer time taken by elderly subjects to reach to the same side. It could be conjectured that elderly subjects have less flexibility than younger subjects. However, less flexibility would imply that more elderly subjects would be unable to transfer as much weight to the side reached to, due to a decreased ability to move into an asymmetrical posture. The results do not support this, as the maximum weight transference of the young and elderly subjects was similar. Alternatively it could be proposed that the longer times exhibited by the more elderly subjects were due to the necessity for the older subjects to move more slowly in order to more achieve control over the COM relative to the BOS. This proposal implies that more elderly subjects may have a lack of ability or problems relating to the control of the COM within the BOS. As this is the first reported investigation of time taken to reach, there are no studies with which these results can be compared.

Although there were no reports of the time taken to complete a reaching task found in the literature, there are a number of studies that report the time taken to perform other functional tasks by healthy subjects. Studies reporting the time to rise to stand indicated that elderly subjects may take longer to perform this function (Wheeler et al, 1985; Engardt and Olsson, 1992; Durward, 1994), although this finding remains inconclusive (Durward, 1994). Further investigations are required to investigate the times taken to perform functional activities by healthy subjects of different ages.

Due to the differences between the time taken by the young and elderly healthy subjects to reach to the same side, to enable comparison with the time taken by hemiplegic subjects the data from the elderly subjects was used. The mean age and age range of the hemiplegic subjects was more similar to those of the elderly subjects than to those of the young subjects.

18.6.3 Hemiplegic subjects

Initial measurements (week 0) demonstrated that the patients with hemiplegia had a median peak symmetry index during reaching to the same side of 0.63. This symmetry index equates with the transference of approximately 81.5% of body weight on to the unaffected side. 90% of the hemiplegic subjects transferred between approximately 64% (SI=0.28) and 91% (SI = 0.82) of body weight on to the unaffected side, compared to values of between 84.5% and 97% for 90% of the healthy subjects. The variation in the ability of the hemiplegic subjects was greater than the variation between the healthy subjects. Some of the hemiplegic subjects achieved weight transference that was well within the healthy subject range; however, large proportions transferred less weight to the side reached to than the healthy subjects. The failure of the majority of the hemiplegic subjects to transfer a "normal" magnitude of weight on to the side reached to implied that many of the hemiplegic subjects had impaired ability to transfer weight onto the unaffected side. It is proposed that this impairment was related to a lack of ability to control the COM towards the limits of the BOS, which subsequently prohibited the subjects from transferring more weight to that side. Studies of weight shifting in stance confirm that the ability of hemiplegic subjects to transfer weight could be impaired in comparison to healthy subjects (Murray et al, 1975; Goldie et al, 1996).

Over the following weeks, the median value of the peak symmetry index during reaching increased for the control group subjects. The magnitude of the increase was relatively small. During weeks 1-6 there was no trend in the change of the 5th percentile, indicating that there was no increase in the minimum weight transferred by the subjects. However, a slight upward trend in the maximum amount of weight transference occurred over these weeks. Thus it appears that, while the ability of some of the control group subjects to transfer weight improved, this was not the case for the entire group. The slight change in the ability of the control group subjects to transfer weight on to the unaffected side was further demonstrated in the exploration of the proportion of subjects whose ability was "abnormal" or "normal" throughout the test weeks. These data did suggest that, while the improvement in ability was slight, there was a definite upward trend in the ability of the control group subjects to transfer weight on to the unaffected side.

In contrast to the observable changes in the peak symmetry index of the control group over the test weeks, there was no apparent trend in the amount of weight transference by the practice group subjects. The slight difference between the control and practice group subjects can be observed both in the values of the medians and percentiles, and in the rating of the ability of the hemiplegic subjects relative to the healthy subjects. However, the proportion of hemiplegic subjects achieving normal weight transference between the first and last measurement was similar for both the control and practice group.

A factor that further challenged the relevance of the observed differences between the ability to weight transfer by the control and practice groups, was the apparent influence of discharge status on the peak symmetry index during reaching to the same side. For both the control and practice group subjects the median peak symmetry index for the subjects not discharged during the study period had no remarkable trend or pattern. However the median peak symmetry indices for the control and practice group subjects who were discharged home or discharged for other reasons had a definite upward trend. It can be surmised that the functional ability of subjects who were discharged home improved more than that of subjects who were not discharged home within 6 weeks of achieving independent sitting balance. This leads to the proposal that ability to transfer weight on to the unaffected side may be related to functional ability.

The low number of subjects who were discharged for other reasons and the different reasons for the discharge preclude generalised conclusions being drawn from the results of these subjects. However, the apparent relationship between discharge status and the peak symmetry index during reaching may provide an explanation for the difference between the trends in the symmetry data for the control and practice group results. No subjects were discharged from the practice group after week 3, while subjects were discharged from the control group until week 5. The greatest difference between the peak symmetry data for the control and practice group occurred during weeks 4 and 5; when subjects who were discharged during the test period remained in the control group but not the practice group. It cannot, therefore, be assumed that the slight differences in the ability to transfer weight between the control and practice group occurred as a result of the practice intervention. Further research is necessary to investigate the relationship between the peak symmetry of weight distribution during reaching and discharge status.

During the week 0 measurement, 90% of the hemiplegic subjects returned to sit after reaching with a maximum of between approximately 64% (SI = -0.28) of body weight on the affected side and 62% (SI = 0.24) on the unaffected side. The median amount of weight taken through the affected side following reaching to the unaffected side was approximately 52% (SI=-0.04). The median value and the percentiles imply that there was, on average, approximately symmetrical weight distribution. For the hemiplegic subjects; during sitting after reaching 90% of the values for the mean symmetry index were within a range of 28% and during quiet sitting 90% of the values for the mean SI were within a range of 17%. For the healthy subjects these values were 14% and 10% for sitting after reaching and quiet sitting respectively. The data suggest that the ability of the hemiplegic subjects to achieve symmetrical weight distribution during sitting after reaching was diminished relative to the healthy subjects.

Over the following test weeks the median symmetry of weight distribution after reaching for the control group subjects had a slight upward trend, starting with weight distribution of approximately 54.5% (SI=-0.09) of weight on the affected side and ending with weight distribution of approximately 54.5% (SI=0.09) to the unaffected side. Despite this apparent trend in the median value, the percentiles demonstrated that there was a relatively large variation in the control group results over the test weeks, the limits of which did not support the existence of an upward trend. Throughout the 7 weeks of testing the maximum weight distributed to the affected side was 63% (SI = -0.26) and the maximum weight distributed to the unaffected side was 68.5% (SI = 0.37), for 90% of the control group subjects. This implies that the increased variation in the symmetry of weight distribution during sitting following reaching was evident throughout the test period for the control group.

For the practice group, during the initial 3 weeks of testing, the symmetry of weight distribution during sitting following reaching was similar to that of the control group. The maximum weight distributed to either side varied from a maximum of 62% (SI =

-0.24) on the affected side to a maximum of 65% (SI = 0.30) on the unaffected side, for 90% of the practice group subjects. However, during the following weeks the practice group subjects appeared to distribute increasing amounts of weight to the affected side during sitting after reaching. During test weeks 4 and 5 over 90% of the practice group subjects all distributed more weight on the affected than on the unaffected side. The tendency for practice group subjects to distribute more weight on the affected than the unaffected side during the latter test weeks is emphasised further in the exploration of the data from subjects tested on all the test weeks.

The increased weight distribution to the affected side by the practice group subjects, and the weight distribution that remained close to symmetrical weight distribution by the control group, was reflected in the comparison of the ability of the hemiplegic subjects with the normal range of the healthy subjects. A substantially greater proportion of the control group than the practice group had normal weight distribution during the test weeks, and there appeared to be a slight upward trend in the proportion of the control group subjects achieving normal weight distribution. There were no apparent trends in the proportion of practice group subjects achieving normal weight distribution during sitting following reaching. The difference in the proportion of control group and practice group subjects achieving normal weight distribution reaches a significant level during week 3 (Chi^2 = 0.016), when the proportion of practice group subjects achieving normal weight distribution was significantly less than the proportion of control group subjects achieving normal weight distribution.

The statistically significant difference between the ability of the control group and practice group implies that the practice intervention had an effect on the symmetry of weight distribution in sitting following reaching. The practice intervention appeared to result in an increase in weight distribution toward the affected side, and subsequently a decrease in the proportion of practice group subjects achieving normal weight distribution, in sitting after reaching. The increase in weight distribution on the affected side did not appear to be a beneficial effect, although the consequence of this effect was not known. The difference between the control group and practice group did not appear to be permanent, as the weight distribution during sitting after reaching for the practice group was more symmetrical during the final test week. The implication of the differences between the control and practice group will be discussed in the following chapter.

The time taken to reach to the same side remained remarkably constant for both the control group and practice group throughout the test period. There were no observable differences between the control group and practice group or trends in the time taken over the test weeks. The minimum time taken for 90% of the control or practice group subjects on any of the test weeks was 6.00 seconds, and the maximum time was 15.85 seconds. These values demonstrate that there was a relatively large variation in the time taken by different subjects. 90% of the elderly healthy subjects took between 5.61 seconds and 11.47 seconds. The length and variation in the time taken by the hemiplegic subjects was not dissimilar to the time taken by the elderly healthy subjects. The upper limit of the times taken by the hemiplegic subjects was slightly greater than the upper limit of the times taken by the elderly healthy subjects, but there was little difference in the lower limit. The high proportion of hemiplegic subjects achieving times within the normal range highlights the similarity in the times taken by the elderly healthy and hemiplegic subjects.

18.7 Reaching across to the opposite side

18.7.1 Analysis of movement

As was the case for the analysis of the movement of reaching to the same side, there were no studies found in the literature that assisted in the identification of pertinent measures of outcome for the analysis of reaching across to the opposite side. The lack of studies in the literature relating to the symmetry of weight distribution meant that there was no available data with which the results of this study could be compared.

The goal for reaching across to the opposite side was, as for reaching to the same side, to achieve the maximum possible *asymmetry* of weight distribution. Although the goals of reaching to the same side and reaching across to the opposite side were similar, there was no available evidence that indicated whether the outcome variables assessed to be appropriate for the analysis of reaching to the same side were also applicable to the analysis of reaching across to the opposite side. In order to identify appropriate measures of outcome, for the analysis of reaching across to the opposite side, the pattern of the symmetry index during the movement was initially explored.

The pattern of symmetry of weight distribution during reaching across to the opposite side was found to be similar, although opposite in direction, to the pattern of symmetry of weight distribution during reaching to the same side. In order to allow comparison of the variables during reaching across to the opposite side with the variables during reaching to the same side, the outcome variables and definitions for the start and end of movement for reaching across to the opposite side were identical to those for reaching to the same side. Although there was no evidence from previous studies that reaching across to the opposite side was related to reaching to the same side, observation and exploration of the raw data indicated that there were similarities between the outcome variables for the two movements. Reaching to the same side as the arm being reached with and reaching across the body with the arm to the opposite side could be argued to be two different functional activities. However, the pattern of symmetry of weight distribution was observed to be similar in both these functional activities. Thus it is proposed that similar patterns of weight transference can be induced, regardless of the method of reaching. The magnitude of the weight transference achieved during reaching across to the opposite side, in comparison to reaching to the same side, provided evidence pertaining to the observations made from the pattern of movement.

18.7.2 Healthy subjects

During reaching across to the opposite side the median difference in weight distribution between the sides for the healthy subjects was approximately 81% (SI = -0.81), indicating that approximately 90.5% of body weight was distributed through the side reached to. There was relatively little variation in the maximum amount of weight distributed through the side reached to, with 90% of the healthy subjects having peak weight distribution through the side reached to of between 83.5% (SI = -0.67) and 96% (SI = -0.92). These values were very similar to the range of peak weight distribution taken through the side reached to during reaching to the same side (90% of subjects between 84.5% and 97%). The magnitude of the peak symmetry index demonstrated that healthy subjects had the ability to transfer a maximal amount of body weight on to the side reached to, regardless of whether the arm had to reach across the body or not. The similarity in the magnitude of weight transference during reaching across the body with the arm and during reaching out to the side without reaching across the body potentially has significant implications for the treatment of patients with hemiplegia. Patients with hemiplegia often have poor control over the affected arm. This study indicates that lateral weight transference on to the affected side – a common goal of treatment (Davies, 1985, 1990; Bobath, 1990) - can be facilitated through reaching with the unaffected arm across the body.

As in the case of sitting after reaching to the same side, the median values for the symmetry of weight distribution during sitting after reaching across to the opposite side indicated that subjects continued to distribute more weight through the side reached to during sitting after reaching. However, unlike the results from sitting after reaching to the same side, the interquartile range of the symmetry index for sitting after reaching across to the opposite side indicated that the subjects did have fairly symmetrical weight distribution during the period of sitting. 90% of the healthy subjects distributed a maximum of 56.5% (SI = -0.13) on the side reached to and a maximum of 55.5% (SI = 0.11) on the opposite side following reaching across to the opposite side. The healthy subject results thus indicated that healthy subjects tended to return to a position with symmetrical weight distribution following reaching to the opposite side. Comparing the symmetry of weight distribution during sitting after reaching across to the opposite side (90% of subjects within a range of 43.5% to 56.5%) with the symmetry of weight distribution during quiet sitting (90% of subjects within a range of 45% to 55%) suggests that the symmetry of weight distribution following reaching was similar to that during quiet sitting. This similarity implies that subjects returned to a normal sitting posture with symmetrical weight distribution following reaching across to the opposite side.

The results from the healthy subjects during sitting after reaching to the same side indicated that there was a slight shift in the results. It was proposed that the shift might be attributed to chance, and that this result would not be repeatable. The identification that during sitting after reaching across to the opposite side healthy subjects demonstrated highly symmetrical weight distribution lends support to the proposal that the shift observed in the data from reaching to the same side was anomalous.

The time taken to reach across to the opposite side by the young and elderly subjects was very similar. 90% of the healthy subjects took between approximately 5.8 and 9.6 seconds to complete the movement. While there were significant differences between the times taken by the young and elderly healthy subjects during reaching to the same side, the times taken by the young and elderly healthy subjects during reaching across to the opposite side were similar. The median time taken to reach across to the opposite side was 7.2s for the young subjects and 7.4s for the elderly subjects (for reaching to the same side these times were 6.8s and 8.3s respectively). However, comparison of the times taken by any of the healthy subjects during reaching to either side, must be carried out with caution, as the distribution of times taken was not normal for any of the groups of subjects. A weak but significant association was found between the time taken to reach across to the opposite side and gender (R^2=0.126, $p<0.05$), with female subjects taking longer to complete the movement. The magnitude of the variation between the times taken between different subjects was large, and it was therefore concluded that further investigation was required to explore the differences in time taken by subjects of different gender during reaching to the same side and reaching across to the opposite side.

18.7.3 Hemiplegic subjects

At the initial measurement of reaching across to the opposite side 90% of the hemiplegic subjects transferred between 64% (SI = -0.28) and 96% (SI = -0.92) of body weight on to the affected side. This was similar to the proportion of body weight transferred on to the unaffected side during reaching to the same side (90% of subjects between 64% and 91%). Some of the hemiplegic subjects achieved weight transference within the normal range of the healthy subjects, while a considerable proportion of the hemiplegic subjects transferred less weight than the healthy subjects did.

The magnitude of the weight transference by the healthy subjects during reaching to the same side and to the opposite side was similar regardless of the direction of reach. Due to hemiplegia it might have been proposed that the similarity in the magnitude of the peak symmetry index during reaching to the same and to the opposite side would not be observed in the stroke patients. However the similarity in the magnitude of weight transference to either side indicated that the stroke patients did not tend to be more impaired during reaching in one direction than during reaching in the opposite direction. Studies of the ability of hemiplegic subjects to laterally weight-shift during stance have demonstrated that hemiplegic subjects have a better ability to transfer weight to the unaffected than to the affected side (Goldie et al, 1986). In contrast, the results of this study indicate that the ability of hemiplegic subjects to transfer weight in sitting was not impaired more in one direction than another. The difference between the results of this study and the results of the studies of weight transference in stance (Goldie et al, 1986) suggests that the ability to transfer weight in sitting and standing may not be related.

The lack of differences between the reaching ability to the affected and unaffected sides is supported by the study by Tanaka et al (1997), which found that trunk rotation by hemiplegic subjects was equally impaired to the affected and unaffected sides. In contrast, Bohannon et al (1995) reported a greater impairment in strength of lateral flexion to the affected side than to the unaffected side. However, Bohannon et al (1995) did find that not all hemiplegic subjects had greater muscle strength on the unaffected side. The results of this study indicate that trunk control is impaired equally on the affected and unaffected sides, and that stroke patients do not tend to be more impaired during reaching in one direction than during reaching in the opposite direction. The similarity between weight transference to the unaffected and affected side observed in this study has implications for physiotherapy; not only as hemiplegic patients have been demonstrated to have equal ability to transfer weight to the affected and unaffected side, but also because this has been demonstrated using the unaffected arm to facilitate the movement in either direction. This study indicates that reaching with the unaffected arm, in either direction, is an appropriate method of facilitating weight transference.

During test weeks 1 – 6 there was little change in the peak symmetry data collected during reaching, with no apparent differences between the control and practice group or trends in the data over the test weeks. However, exploring the proportion of hemiplegic subjects achieving normal peak symmetry indices over the test weeks indicated that the ability of the practice group subjects was greater than that of the control group subjects. The differences in the proportion of control group and practice group subjects achieving normal weight transference, despite the lack of apparent differences between the symmetry data, was explained by the degree of overlap between the hemiplegic data and healthy subject data. Although the median and interquartile ranges of the control group and practice group were similar over the test weeks, the range of values for the control was greater than that of the practice group, with a shift in the range toward a lower (less negative) symmetry index. The shift in the control group data resulted in a lower proportion of the control group subjects being within the "normal" range. The lower proportion of control group subjects with weight transference in the normal range suggested that the ability of the practice group subjects was different to that of the control group subjects. However, due to the low number of subjects in the study, one of two outliers within the control group could explain the apparent difference between the control group and practice group. Further research is necessary to investigate whether this difference is due to random chance or whether the ability of the practice group was greater than that of the control group.

During the week 0 measurement, 90% of the hemiplegic subjects returned to sit after reaching across to the opposite side with between 63% (SI = -0.26) of body weight on the affected side and 62% (SI = 0.24) on the unaffected side. The median amount of weight taken through the affected side during sitting following reaching to this side was approximately 53% (SI = 0.06). The median and percentiles imply that there was, on average, approximately symmetrical weight distribution with a maximum of approximately 26% difference in weight distribution between the sides. This was very similar to the distribution of body weight during sitting after reaching to the same side (where 90% of subjects had 28% difference in weight distribution between the sides).

Both the control and practice group demonstrated greater variation than the healthy subjects, with the greatest asymmetry occurring with more weight on the affected than on the unaffected side, on all test weeks. 90% of the control group subjects distributed a maximum of 75.5% (SI = -0.51) of body weight on the affected side and a maximum of 64% (SI = 0.28) of body weight on the unaffected side, during any of the test weeks. For the practice group these values were 71.5% (SI = -0.43) and 59.5% (SI = 0.19) respectively.

While the median value of the symmetry index for the control group remained close to that of the healthy subjects throughout the test weeks, the practice group median value indicated that the practice group tended to distribute more weight to the affected side than to the unaffected side. The tendency to distribute more weight to the affected side than the unaffected side increased over the test weeks, and in weeks 4, 5 and 6 90% of the practice group subjects all distributed more weight to the affected side than to the unaffected side. The differences between the control group and practice group were highlighted by the proportion of control group and practice group subjects achieving normal weight distribution during sitting after reaching. There was little difference in the proportion with normal and abnormal weight distribution between the control and practice group during weeks 0 and 1; however in weeks 2-6 a greater proportion of control group subjects achieved normal weight distribution. This difference reached significance in week 4 ($Chi^2 = 0.027$).

Interestingly the difference in the weight distribution during sitting after reaching across to the opposite side between the control group and practice group demonstrated a similar pattern of results as was found for sitting after reaching to the same side. During both sitting after reaching to the same side and sitting after reaching across to the opposite side, the practice group subjects distributed increased weight to the affected side during the later test weeks. For both functions there was a significant difference in the proportion of control and practice group subjects achieving normal weight distribution during one of the test weeks. The statistically significant differences between the control group and practice group imply that the practice intervention increased the tendency for weight bearing through the affected side following reaching. The tendency for weight bearing through the affected side during sitting after reaching appears to occur regardless of the direction of the reach executed.

One of the problems following stroke frequently referred to in the literature is asymmetry of posture and weight distribution in sitting (Bobath, 1978, 1990; Davis, 1985, 1990; Carr and Shepherd, 1989, 1992; Ashburn, 1997). It has frequently been assumed that patients with hemiplegia tend to favour their unaffected side (Bobath, 1978, 1990; Davis, 1985, 1990). The results of this study suggest that the practice intervention can increase the weight distribution toward the affected side; however this results in the subjects demonstrating asymmetry of weight distribution to the affected side rather than demonstrating symmetry of weight distribution that is, on average, symmetrical. Such a finding challenges whether the practice intervention was beneficial or, indeed, detrimental. However, the results of this study also identified even more fundamental questions pertaining to the rehabilitation of subjects with stroke. These questions relate to the pathophysiology behind the adoption of asymmetry of weight distribution and whether subjects have the ability to regain normal posture and movement. Further research is essential to identify normal patterns of recovery of patients with stroke and the relationship of factors relating to the symmetry of posture and movement and functional outcome. The difference between the control and practice group is further explored in the following chapter.

Exploration of the time taken to reach across to the opposite side demonstrates that there was no apparent trend in the results over the test weeks, or differences between the time taken by the control group and practice group subjects. 90% of the hemiplegic subjects took between 5.94 seconds and 15.13 seconds to reach throughout the test weeks. The upper limit of the time taken by the hemiplegic subjects was substantially more than the upper limit of the time taken by the healthy subjects; 90% of the healthy subjects took between 5.75 and 9.58 seconds. As in reaching to the same side, there was a large variation in the time taken by hemiplegic subjects to reach across to the opposite side. However, there was a significant positive relationship ($r = 0.76$) between the time taken to reach to either side by the hemiplegic subjects. The association between the time taken to reach to either side indicated that the time taken by the hemiplegic subjects was not random, but was reflective of subjects' functional ability. It has been proposed in the literature that the time taken to perform functional tasks can be reflective of more global functional ability (Durward, 1994): the apparently non-random nature of the time to reach suggests that the time taken during reaching may be related to patients' ability.

Unlike the time taken to reach to the same side, there was greater difference in the upper time limit taken by the healthy subjects and the hemiplegic subjects. This difference was reflected in the proportion of hemiplegic subjects whose time was within normal limits during reaching. A relatively small proportion of control and practice group subjects achieved normal time limits for reaching across to the opposite side, in contrast to the relatively large proportion for reaching to the same side. This difference between the ability of the hemiplegic subjects to perform reaching to the same side and reaching across to the opposite side within the normal time limits indicates that the stroke patients may have had more difficulty during reaching across to the opposite side than during reaching to the same side. Although the magnitude of the weight transference was similar during reaching to the same side and reaching across to the opposite side, the time taken to complete reaching across to the opposite side was longer. The differences in the ability for the two movements suggest that subjects with stroke have more difficulty executing the movement of reaching across to the opposite side than reaching to the same side. An increased amount of rotation required during reaching across to the opposite side; an increased necessity to control muscle groups on the affected side; or a decrease in the ability to control the COM within the limits of the BOS on the affected side, could all provide potential explanations for the difference in the ability to reach to the same side and to reach across to the opposite side. Further research is necessary to explore the differences in the ability to transfer weight to the unaffected and affected side.

18.8 Functional ability

18.8.1 Comparing functional tasks

The association between the symmetry index during stance and the seat-off phase of sitting down, and between the symmetry index during the seat-on phases of rising to stand and sitting down, were found to have high and fair correlation respectively, for the healthy subjects. Both stance and the seat-off phase of sitting down involve an upright posture with a relatively small BOS; both the seat-on phases of rising to stand and sitting down involve movement within the sitting posture. The similarities between these functions provide an explanation for the association between the symmetry of weight distribution during their execution. However the association between these variables was not significant, with the significance level of the variables in the regression equations being less than 95%. There were no other significant correlations between the different functions for the healthy subjects. The relatively low variation between the symmetry values for all the tasks, and the finding that, for many tasks, the variability between the subjects was similar to the variation between repeated measures precluded correlation between the variables. The variation between some of the timed measures was greater than the variation between the symmetry variables. However it was still found that repeated measures tended to vary throughout the range, making the chances of association between timed variables low.

There were significant associations found between variables for the hemiplegic subjects. There was a significant and fair correlation between the symmetry of weight distribution during stance and the symmetry of weight distribution during the seat-off phase of sitting down. It is interesting to note that these variables were correlated, although not significantly, for the healthy subjects. For the hemiplegic subjects this significant association implied that subjects distributing increased weight to the unaffected side during stance would also do so during the seat-off phase of sitting down, and vice versa. This finding led to the conclusion that the hemiplegic subjects had a preferred side for weight bearing rather than the asymmetry occurring randomly. It can be suggested that the asymmetry of weight bearing during these tasks, which involve a small BOS and thus create a challenge to balance, may occur due to an impairment in the ability to control the COM within the centre of the BOS. Alternatively it could be suggested that the asymmetry of weight bearing might occur due to a lack of motor control on the affected side resulting in a dependency on the unaffected side, and thus a greater vertical force applied through the unaffected side in order to generate sufficient muscular activity for posture and movement. The finding of a significant association between symmetry variables indicated that asymmetry was not occurring randomly and supported the existence of a preferred side of weight bearing, thus indicating that the asymmetry might be directly related to the motor control over the affected and unaffected sides of the body.

The lack of studies in the literature reporting measurements of the symmetry of weight distribution during a number of postures and movements prevented direct comparison of the results from this study with results in the literature. However, a significant correlation between the symmetry of weight distribution during stance and the position of the COP during lateral weight shifting in stance was reported by Dettmann et al (1987). This implied that there might be a relationship between the ability to weight shift and the symmetry of weight distribution during the maintenance of a posture. The lack of association found in this study between the symmetry of weight distribution during sitting and the peak weight transference during lateral weight shifting in sitting was unable to support the results of Dettmann et al (1987). However, as has been identified in the review of the literature, it cannot be assumed that measures of the position of the COP and measures of weight distribution during weight shifting are related. This emphasises the limitations arising from the lack of knowledge pertaining to the different methods of measuring aspects of balance.

A significant association was also found between timed variables, with hemiplegic subjects taking longer to reach to the same side also taking longer to reach across to the opposite side. This association suggests that rather than the time taken to reach by the hemiplegic subjects varying randomly through a specified range, the times taken to reach were specific to the individual subjects. The association between the timed reaches infers that the time taken to reach to either side might be related to an independent factor pertaining to the nature of stroke or the stage in recovery. During the review of the literature the validity of duration taken to reach as a measure of functional recovery was challenged. However, the results of this study appear to support the use of time taken to reach, reported by Dean and Shepherd (1997), as an indicator of functional improvement. Further investigation is necessary to determine whether the time taken to reach has any associations with independent variables. It has been identified that simple timed tests are useful clinical indicators of gait performance (Wade et al, 1985a) and it has been proposed that the time taken to rise to stance and sit down represents a basic but fundamental indicator of functional status in stroke patients (Durward, 1994). The limited results of this study therefore support the argument that accurate measures of time taken to perform functional activities may prove to be basic indicators of functional ability in stroke patients.

18.8.2 Functional ability score

The FAS incorporated all 14 outcome variables, which included symmetry values from both symmetrical and asymmetrical tasks and time variables. Arguably a "symmetrical ability score" (SAS) assessing the ability of subjects to achieve symmetrical weight distribution during the symmetrical tasks (sitting, standing, rising to stand, sitting down) could have been a more appropriate assessment of total ability to achieve and maintain a symmetrical posture. Similarly a "timed ability score"

(TAS) assessing the ability of subjects to achieve normal time to complete tasks (rising to stand, sitting down, reaching to the same side, reaching across to the opposite side) may have been a more appropriate assessment of the ability to control a task over time. Limited exploration was carried out to explore the association between the FAS, SAS and TAS. The FAS, SAS and TAS were each calculated for each subject on each test day. Spearman's rho was computed to determine the degree of correlation between these 3 different scores of ability. These are displayed in Table 18.1.

	FAS	SAS	TAS
FAS	1.000	0.940	0.762
SAS	0.940	1.000	0.786
TAS	0.762	0.786	1.000

Table 18.1 Spearman's rho for association between scores of ability (significant at 0.01 level).

There was a high association between the FAS and the SAS and a fair association between the SAS and TAS, and FAS and TAS. An association between the FAS and SAS and between the FAS and TAS was expected, as the variables included in the SAS and TAS were also included in the FAS. However, the same variables were not included in the SAS and the TAS. The relatively high correlation between the scores indicated that the scored outcome variables were assessing similar aspects of ability. The next stage in the analysis of such associated variables would have been to determine whether any of the 14 outcome variables were redundant in the assessment of ability. This process could be carried out using a process of Factor Analysis to determine the relative strengths and influences of the individual outcome variables on the ability score. However this process requires a large sample size (Bryman and Cramer, 1990). Factor Analysis could not therefore be carried out with the results from this study. Although Factor Analysis, with the results from a larger sample, may have identified that some of the outcome variables used in the FAS were redundant and that an alternative score, using less variables, may have been appropriate, this remained unknown. The functional ability of the hemiplegic patients was therefore assessed using all 14 outcome variables (FAS). While this score may have been heavily weighted by the symmetry variables, and weighted less by time and asymmetry variables, it was argued that the FAS was most likely to be sensitive to a change in ability. Further exploration of the use of the symmetry and time variables to develop a score of functional ability is required.

For both the control and practice group subjects the FAS tended to increase between week 0 and week 2 and then remain relatively unchanged for the remainder of the test weeks. The increase between weeks 0 and 2 was proposed to be due to the number of subjects who became able to stand, rise to stand and sit down during these weeks. Evidence was provided for this in chapter 10, where the number of subjects tested performing each of these tasks can be observed to increase between weeks 0 and 2 and remain relatively unchanged thereafter. Additional evidence for the effect of the number of subjects able to stand, rise to stand and sit down on the FAS was found when the pattern of change of the proportion of subjects achieving these tasks was compared with the pattern of change of the FAS (section 17.2.3). There was a remarkable similarity in the pattern of change of the proportion of subjects achieving these tasks and the pattern of change of the FAS, for the control group and practice group. This high degree of similarity leads to the proposal that an increase in the ability to carry out standing, rising to stand and sitting down may have been the only measured improvement in ability over the 6 weeks of physiotherapy. With the exception of the increased numbers achieving these functions during weeks 0, 1 and 2, there was no evidence to indicate that there was any tendency for improvement in the ability to perform the assessed functional tasks within the "normal" limits during the test period. It can be concluded that during the first 2 weeks of physiotherapy treatment there was an increase in the number of subjects able to perform tasks involving a smaller BOS. During the subsequent 4 weeks of physiotherapy treatment there was no apparent change in the ability of the hemiplegic subjects to perform the assessed functional tasks.

The increase in the FAS for subjects discharged home during the study period occurred between weeks 0 and 1, while the increase in the FAS for subjects completing all 7 test weeks occurred between weeks 1 and 4. It is predicted that the difference between subjects who were and who were not discharged may be related to independent variables, and thus that there may be associations between the FAS and independent variables. Although the rate of change of the FAS varied in different groups of subjects, the change in the FAS could still be directly related to the achievement of stance, rising to stand and sitting down rather than changes in the ability to perform the tasks within the "normal" range. In both groups of subjects a point was reached where no further change in the FAS occurred. It is proposed that in both groups the initial change in the FAS was related to the achievement of stance, rising to stand and sitting down, and the lack of change in the following weeks was due to a lack of improvement in the numbers of subjects able to perform the functional tasks within the normal limits.

The functional tasks that were assessed were chosen as they reflected the generalised aims of physiotherapy for the acute stroke patient. The classification of unable, abnormal or normal was selected, as a key aim of physiotherapy is to return the hemiplegic patients to having "normal" posture and patterns of movement. There was no evidence provided from this study that patients with stroke improved in the ability to perform the selected tasks in a "normal" manner. Thus this study was unable to confirm that the aims of physiotherapy were met during the 6-week period of in-patient treatment. The implications of this to physiotherapy practice are discussed in later chapters.

18.8.3 Functional ability and independent variables

A significant, but poor, association was found between the Barthel Index and the FAS. The graph plotting the FAS against the Barthel Index (Figure 16.9) indicated that, although there was an observable positive relationship, there was a large amount of variation around the regression line. It has previously been suggested that changes in the FAS over the test weeks tended to occur as the subjects achieved the ability to stand, rise to stand and sit down. The functions assessed in the Barthel Index could be argued to include functional items that would be influenced by subjects' ability to stand, rise to stand and sit down. For example, the subjective assessment of a patient's dependence during the activities of a chair / bed transfer, toiletting, mobility and stairs, included in the Barthel Index, may all be associated with ability to stand, rise to stand and sit down. The association between the FAS and the Barthel Index infers that both the FAS and the Barthel Index were influenced by whether a subject was able or unable to perform a functional task, but that the ability of the subject to perform the task within the normal limits of human movement did not influence these scores. However, unlike the Barthel Index, the nature of the FAS was such that it did have the potential to detect changes in the ability of subjects to perform functions within the normal limits. Since the aims of physiotherapy are directly related to the functions assessed by the FAS and to the method of assessing the ability relative to the normal, it is proposed that the FAS may be a more appropriate and sensitive outcome score than the Barthel Index. Further exploration of the FAS, including Factor Analysis, is necessary to assess the potential of the FAS as an indicator of functional ability and as an assessor of the achievement of the aims of physiotherapy.

Differences were noted between the FAS of subjects with left and right hemiplegia over the test weeks. The FAS of the right hemiplegics increased more rapidly than that of the left hemiplegics; with the right hemiplegics reaching a relatively unchanging maximum score in week 1, and the left hemiplegics in week 2. The median score of the left hemiplegics remained lower than that of the right hemiplegics on all test weeks. Although the FAS was relatively similar in week 0 for subjects with left and right hemiplegia, the proportion of subjects whose ability improved was substantially greater for the right hemiplegics than the left hemiplegics on all test weeks. Lesions within the left and right hemispheres can result in specific deficits. It was identified, in the review of the literature, that right hemiplegia (damage to left hemisphere) tends to be associated with disorders in language, specific perceptual disorders and apraxia, while left hemiplegia (damage to right hemisphere) tends to be associated with major perceptual dysfunction, such as visual spatial neglect, tactile perceptual disorders and constructional apraxic deficits (Wade et al, 1985a). The perceptual dysfunction associated with right hemisphere lesions can result in the failure of patients to perceive spatial relationships (Rode et al, 1997). A failure to perceive spatial relationships could feasibly manifest as an inability to maintain symmetrical alignment and weight distribution, and to control the COM within the BOS. The lower functional ability in subjects with left hemiplegia found in this study was therefore supported by the nature of the dysfunction occurring following damage to the right hemisphere.

Few differences in functional recovery between patients with left and right hemiplegia can be identified in the literature (Wade et al, 1985a), although studies of motor control and performance following hemispheric damage have demonstrated differences relating to the side of the lesion (Kimura, 1977; Haaland et al, 1987;

Winstein and Pohl, 1995; Rode et al, 1997). This study did identify observable differences in the FAS and change in FAS of the left and right hemiplegics on different test weeks, although the range of values was relatively large and there was considerable overlap between the functional ability of the subjects with left and right hemispheric damage. The differences in the median values for the left and right hemiplegics do suggest that the FAS was sensitive to differences in the functional ability of subjects with damage to the left or right hemisphere. It could be argued that differences have been identified in this study as, as in the work of Haaland et al (1987), Kimura (1977) and Winstein and Pohl (1995) and in contrast to the work reported by Wade et al (1985a), the outcome variables were specific to sensori-motor dysfunction and to the potential variations between subjects with left and right hemiplegia. Further studies are required to investigate the relationship between the side of lesion and functional ability.

Comparing the FAS of subjects with different stroke classifications was made difficult due to the relatively low number of subjects with each stroke classification. Comparing the FAS of subjects with TACI against the FAS of subjects with other stroke classifications demonstrated that the FAS of the TACI group improved more rapidly and the median value tended to be greater. Observing the median values and the change in FAS from week 0 to the other weeks indicates that the functional ability of the TACI group and LACI group were similar and remarkably greater than that of the PACI group. The low number of subjects with POCIs and PICHs preclude generalisation of these results. The greater functional ability of the TACI group than the PACI group was not supported by the classification system, which defined more severe lesions as TACIs and less severe as PACIs (Bamford et al, 1991). Studies in the literature have generally reported that patients with more severe lesions (TACIs) have a worse functional ability and outcome than patients with less severe lesions (Sackley and Gladman, 1998; Smith and Baer, in press). The findings of this study are therefore not supported by the evidence pertaining to stroke classification in the literature. There is no scientific evidence that explains the anomaly of the greater functional ability of the TACI group found in this study. This was a small-scale study with relatively low numbers of subjects. It is possible that a sample with an uneven ratio of independent variables, for example side of hemiplegia, between subjects with different stroke classification may have resulted in such an anomalous result. Studies of functional ability have demonstrated the opposite to the results in this study, finding the functional outcome of patients classified as PACI, LACI and POCI to be similar, and substantially greater than the functional outcome of patients classified as TACI (Smith and Baer, in press). However, studies in the literature have tended to assess ability using assessments of ability to achieved functional goals, rather than measures of the quality of achieving functional goals. The lack of assessment of the quality of the functional movement in studies reported in the literature prevents direct comparison of these studies with the measures of FAS, which assessed the quality of the movement and postures. Further research, with larger sample sizes, is therefore necessary to explore the relationship between the FAS and stroke classification.

18.9 Summary and conclusions

18.9.1 Healthy subjects

- Healthy subjects generally distributed between 43% and 57% of body weight to either side during sitting, standing, rising to stand and sitting down.
- Healthy subjects generally distributed a maximum of between 83% and 97% of body weight on one side during lateral reaching.

18.9.2 Hemiplegic subjects

- Hemiplegic subjects demonstrated greater asymmetry of weight distribution than the healthy subjects during sitting, standing, rising to stand and sitting down, with a preference for weight bearing through the unaffected side.
- Hemiplegic subjects distributed a similar proportion of weight to the unaffected and the affected side during lateral reaching.
- There was a generalised lack of change in the ability of the hemiplegic subjects to perform the assessed tasks over the test weeks.
- There were significant differences in the symmetry of weight distribution during sitting after reaching between the control group and the practice group. The consequences of these differences are not known.

19. Discussion: Effect of independent practice

19.1 Introduction

This chapter identifies the differences in functional ability between the patients carrying out the regime of independent practice (practice group) and the patients who received standard physiotherapy only (control group). The implications of the differences between the control group and practice group are identified, and the effectiveness of the regime of independent practice is discussed. Based on the results of the clinical trial, the evidence for motor learning in patients with acute stroke is commented upon and the practical implementation of a regime of independent practice within a clinical setting is reviewed.

19.2 Differences between control and practice group

This study found that there were no significant differences detected between the control and practice group for the majority (12 out of 14) of the outcome variables over the test period. The variables for which there were no notable differences between the groups were:-

- Symmetry of weight distribution during sitting;
- Symmetry of weight distribution during standing;
- Symmetry of weight distribution during seat-on phase of rising to stand;
- Symmetry of weight distribution during seat-off phase of rising to stand;
- Symmetry of weight distribution during seat-off phase of sitting down;
- Symmetry of weight distribution during seat-on phase of sitting down;
- Weight transference during reaching to the unaffected side;
- Weight transference during reaching to the affected side;
- Time taken to rise to stand;
- Time taken to sitting down;
- Time taken to reach to the unaffected side;
- Time taken to reach to the affected side.

There were differences detected between the control and practice group for 2 of the outcome variables, with the differences being significant during one test week for each variable. These variables were the symmetry of weight distribution during sitting after reaching to the unaffected side and during sitting after reaching to the affected side. The lack of difference between these variables for the control and practice group during the initial test weeks, the existence of the largest (most significant) differences during test weeks 3 and 4, and the smaller differences (less significant) during test week 6, all indicate that the practice was directly responsible for these differences. The greatest differences occurring in weeks 3 and 4 suggests that the practice had a cumulative effect. The reduction in the difference between the control and practice group during the final test week suggests that the effect of the practice was not permanent.

The one effect of the practice regime was, therefore, to increase the amount of weight distributed through the affected side during sitting following maximal weight transference to the unaffected or the affected side. It was hypothesised that the practice regime would result in the outcome variables of the practice group becoming more similar to those of the healthy subjects. This did not occur. The consequence of the increase in weight distribution to the affected side during sitting after reaching is not known. There is no evidence to suggest whether this change was beneficial, detrimental or of no consequence to the functional outcome of the practice group subjects. However, despite the lack of knowledge pertaining to the consequence of the change effected by the independent practice, it can be concluded that independent practice did effect a change in motor performance. This study was not able to conclude that the practice regime effected a change in motor learning, as the change in motor performance was not sustained during the retention tests.

In summary; the results of the clinical trial indicate that the practice regime had relatively little influence on the outcome variables of the practice group. However the practice regime did effect a change in the ability of the practice group, resulting in a small, but significant, temporary increase in the weight distributed to the affected side during sitting after reaching. The following sections discuss the possible reasons for the lack of difference between the control group and practice group for the majority of the outcome measures, and the implications of the changes in motor performance that were effected by the practice regime.

19.3 The practice regime

There are four broad reasons that could potentially explain the lack of motor learning resulting from the practice carried out by the hemiplegic subjects. These are:

1. The implemented practice regime did not promote optimal motor learning.
2. The motor tasks practised were inappropriate for effecting permanent change in the motor performance of the specified motor skills.
3. The environmental context of the patients did not promote optimal motor learning.
4. The process of motor learning is inappropriate for effecting permanent change in the motor performance of individuals with neurological damage.

The following sections will address each of these potential explanations for the lack of motor learning effected by the independent practice implemented in this study.

19.3.1 The practice regime and optimal motor learning

The evidence pertaining to the optimal learning of motor skills was reviewed in Chapter 4.2. It is important that a subject practising a skill recognises the purpose of the skill and has the motivation to practice and learn it (Schmidt, 1991; Magill, 1993). The purpose of the practice regime was explained to each subject participating in the practice group, and the importance of gaining control over movement in sitting was stressed. However, it could be argued that the motor tasks practised by the hemiplegic subjects did not have an immediate and apparent association with functional ability and the recovery of ability to perform activities of daily living. Thus the goals of the practice may not have been meaningful (Magill, 1993) to the subjects.

Following stroke, patients have many disabilities and impairments (Wade et al, 1985b). The subjects carrying out the practice regime all had relatively severe physical dysfunction that resulted in a decreased ability to maintain or achieve sitting balance and severely impaired mobility. The priorities of the patients in the practice regime may therefore have been related to the recovery of functional independence and mobility. A failure to comprehend the theoretical relationship between the goals presented by the practice regime and functional recovery may have reduced the motivation of patients to carry out the practice regime. Deficits in communication and cognition, occurring as a result of the stroke, may also have limited the patients' comprehension of the relevance of the motor skills practised.

Objective, quantifiable goals are more effective than abstract goals (Magill, 1993). The motor tasks practised by the practice group subjects were all objective and quantifiable. However the tasks involved reaching "as far as you can", rather than having a specific quantifiable goal. Thus, although the goal attained could be quantified, the subject was not presented with a quantifiable goal at the start of a motor task. It could be argued that to ensure the objectivity of the task, the subject should have been presented with a set quantified goal. Due to the experimental nature of the practice regime used in this study, there was no evidence available that could be used to set highly specific quantified goals that would be attainable by the hemiplegic subjects. However the evidence gathered by this study, pertaining to distance and height of reach following acute stroke, could be used to set more objective quantifiable goals in future studies (details of distance and height during practice regime are provided in Appendix L).

The general goal of the practice was to improve the ability to achieve and maintain symmetrical alignment in sitting and to improve the ability to control the COM during voluntary movement within sitting. This was a broad goal and the "voluntary movement within sitting" could potentially have involved a myriad of activities. However, the motor tasks were developed to ensure that the regime involved practising the "whole" task (Marteniuk, 1979; Schmidt, 1988, 1991; Magill, 1993). Despite ensuring that each of the tasks involved voluntary movement of the COM within the BOS, the motor tasks practised were limited to tasks involving reaching with the unaffected arm. The degree to which learning to control the COM during reaching can be transferred to other tasks requiring control of the COM, and the degree to which control of the COM during reaching is specific to the learning of control during reaching, will be central to the motor learning resulting from the practice regime. Although the whole task of reaching was practised it is not known if this practise was specific to reaching, or whether there could be transfer of the ability to control the COM during reaching to the ability to control the COM during other seated tasks. The only measured outcomes in which any change in ability was determined due to the practice were directly related to reaching, suggesting that there was no transfer between the ability to control the COM during reaching and the ability to control the COM during other activities. A lack of transference between the ability to control the COM during different postures and movements could have fundamental implications for physiotherapy intervention.

As suggested in the literature (Schmidt, 1988; Magill, 1993), the implemented practice regime used a massed practice schedule. The research indicated that random practice schedules lead to better retention of learning than blocked practice schedules (Shea and Morgan, 1979; Lee and Magill, 1983; Schmidt, 1988, 1991; Lee et al, 1991). However, the use of random practice schedules was limited by a number of factors. The development process identified that the tasks should involve movement across the midline, rather than repetitive reaching to one side: this prevented the presentation of tasks in an entirely random manner. In addition, the practice regime had to be able to be carried out by the hemiplegic subject independently and the regime had to be suitable for execution within a hospital environment. This further limited the amount of randomisation of practice that could practically and feasibly be included in the regime. The use of computerised equipment could potentially have generated random goals during each practice session; however this was beyond the resources of this study. The tasks had to be presented to the subject in a manner that encouraged independence; the development procedure identified that blocks of practice of different tasks were necessary to reduce the amount of supervision and prompting required by the patients. However, in an attempt to produce variability in the tasks practised within each block, the angles and heights of reach were varied using a combination of both random and systematic variation. Although the use of computerised equipment to generate random motor tasks may have promoted more optimal motor learning, it is proposed that the methods utilised within the practice regime to generate variation of practice promoted optimal motor learning within the given constraints of the resources of the study.

The majority of studies described in the literature involve the investigation of healthy individuals during the acquisition of specific, discrete, novel tasks. The tasks investigated can vary considerably in their complexity and in the motor sequences required. Consequently, conclusions regarding the influence of the number of repetitions of a task within each practice schedule, the length of each practice schedule and the number of practice schedules over time cannot be derived from the literature the literature. There is no evidence to suggest the amount of independent practice of any particular task required to effect a change in motor performance or in motor learning. The number of repetitions in studies with healthy subjects have had little consistency; varying from studies reported by Lee et al (1991) using 36 trials, to a study by Shea and Kohl (1990) using 289 trials. Only one of the practice group subjects attended all 20 of the desired practice sessions (5/week for 4 weeks). None of the subjects completed the maximum number of 203 repetitions during any of the practice sessions. The primary reason for the lack of attendance was tiredness, as was the reason for the failure to complete the 203 repetitions during each session. These results imply that the aimed practice schedule was not appropriate for these patients.

From the profile of attendance and number of repetitions completed it is suggested that practice sessions involving fewer repetitions are required. It is proposed that a greater number of practice sessions per day, each involving fewer repetitions, may be appropriate for this patient group. It is also suggested that if the timing of the practice sessions was more flexible than during this study the attendance rate might improve. It was found that the patients had periods of each day when they were tired or had other activities to complete (for example, other appointments, visitors, bathing). If the practice sessions were completed at times convenient and appropriate to the individual patient it is likely that the numbers of both sessions attended and repetitions completed would increase. Thus this study has identified several pertinent points for future studies of motor learning for stroke patients.

The extrinsic feedback provided to the subjects during the practice regime was limited to knowledge of results, comprising verbalised feedback relating to the success of the motor tasks, such as the height and distance of reach and the score attained. Knowledge of performance, giving details of the correct kinematics of the desired movement, was not provided, as the aim of the study was to develop a practice regime that could be carried out independently, supervised by an untrained assistant. It can be argued that the failure to provide knowledge of performance, or any form of guidance, may have limited the results of the practice regime.

It has been identified in the literature that plastic changes within the CNS may not all be beneficial (Bach-y-Rita, 1981b; Dombovy and Bach-y-Rita, 1988; Dombovy, 1991). The Bobath Approach suggests that the experience of "abnormal" afferent input, through the execution of unnatural patterns of movement, can be detrimental to functional recovery (Davies, 1985; Bobath, 1990). The absence of the provision of knowledge of performance in this study may have resulted in the subjects having inadequate information about the pattern of the required movement, and a subsequent failure of the subjects to modify the movement patterns. This could have resulted in the repeated practice of incorrect kinematic sequences and potential detrimental plastic changes.

Carr and Shepherd (1989a) emphasise that the Motor Learning approach for individuals with neurological deficits involves the assessment of movement and identification of missing movement components followed by practice of the missing components by the patient. Thus the Motor Learning approach requires the identification and re-education of specific kinematic components of a movement for each individual subject (Carr and Shepherd, 1989a). Although the implemented practice regime was aimed at addressing a specific problem common to all the stroke patients recruited to the study, no attempt was made to identify and address specific kinematic problems in each individual subject. It could be argued that the failure to identify and address specific kinematic problems and to provide adequate knowledge of performance limited the required modification of movement patterns, and thus restricted changes in motor performance and, consequently, motor learning.

19.3.2 The practice regime and the specified motor skills

The lack of improvement in motor performance resulting from the practice regime may be related to the nature of the motor skills practised. The majority of studies reported in the literature have investigated the motor performance and learning of highly specific, discrete, novel tasks. In these studies, the discrete nature of the task means that the task to be learnt is synonymous with the task to be practised. However, in this study, the aim was to improve the sitting balance of subjects with stroke. Balance has been identified to be a multidimensional concept for which there is no universally accepted definition (see chapter 2). Loss of balance control in sitting has also been identified to have several presentations (Bobath, 1978, 1990; Davis, 1985, 1990; Carr and Shepherd, 1989a,b, 1992; Ashburn, 1997). The multidimensional nature of balance and the variations in the presentation of problems with sitting balance mean that there was no one specific task that could be practised in an attempt to improve motor performance relating to sitting balance.

In order to increase the specificity of the tasks to be learnt, specific aims of the practice of sitting balance were defined (section 9.2.1). Despite the creation of clearly stated aims, based on the available literature, the nature of the practice required to meet these aims remained elusive. There was no evidence in the literature that indicated the specific nature of motor tasks to be practised in an attempt to meet the stated aims. Consequently, the practice regime that was constructed to meet the stated aims was developed through a process of scientific exploration. It could be argued that the lack of objective evidence relating the developed motor tasks included in the regime to the specified aims of the practice meant that the motor tasks practised were inappropriate to meet the aims of the practice. This would imply that the lack of change in motor performance and lack of motor learning could be due to the practice of inappropriate motor tasks.

A small, but significant, change was detected in two of the outcome variables that were specific to the nature of the tasks practised. Although a change was measured, it was not apparent what the consequence of this change was. If the subjects were repeatedly practising a task that encouraged the use of an abnormal pattern of movement, this abnormal pattern of movement may result in detrimental changes to motor performance. Thus, while this study has demonstrated that the independent practice of the developed motor tasks has the potential to create small changes in motor performance, the importance of practising carefully selected and developed motor tasks has also been highlighted. It is proposed that exploration of the kinematics of the relevant movement, using objective measurement tools, may be necessary to ensure the development of motor tasks appropriate for independent practice.

The clinical symptoms that occur following stroke are dependent on the size and location of the area of disrupted blood supply, and the anatomical structures which are involved (Ryerson, 1996). Consequently the clinical symptoms of each individual subject with stroke will be different. Although it has been identified that a common problem following stroke is related to the maintenance of sitting balance (Brunnström, 1970; Lane, 1970; Bobath, 1978; Davies, 1985; Borello-France et al, 1988), the wide-ranging variations in clinical symptoms emphasise that the problems relating to sitting balance may not be synonymous in different subjects. The wide-ranging variations between individual subjects infer that the ability of each subject should be assessed individually, and personalised motor tasks to be practised should be identified for each individual. Alternatively, in the same manner in which patients can be classified according to the nature of the neurological lesion (Bamford et al, 1991), it is proposed that it may be possible to classify patients according to the specific presentation of the balance deficits in sitting. Further investigation of the nature and presentation of balance deficits in different subjects is necessary to address these proposals.

Interestingly, the study by Dean and Shepherd (1997) was relatively similar to this study, involving a training regime comprising reaching tasks aimed at improving sitting balance. Dean and Shepherd (1997) found beneficial changes in motor performance in the stroke patients in the practice group, reporting changes that included an increased distance of reach and an increase in the ground reaction force (GRF) under the affected leg during reaching and during rising to stand. However, a review of the study questioned the validity of several aspects of the study design, including the effects of researcher bias, the ability to generalise from these results and the lack of retention tests. Hence the results from the study reported by Dean and Shepherd (1997) have to be interpreted with care.

19.3.3 The practice regime and the environmental context

Although the regime of independent practice was developed based on the evidence for optimal motor learning, it was not possible to address the overall context within which the practice regime was implemented. The patients involved in the study were all in-patients on a hospital ward. The activities of the patients during times other than the one-hour practice session, five days per week, were out with the control of this study. In relation to the time spent carrying out the regime of independent practice, the time spent in other environmental contexts and situations was substantially greater. Previous studies have identified, from systematic observation of patient activity, that out with periods of therapy stroke patients tend to participate in little activity and have low contact with hospital staff (Lincoln et al, 1996).

The patients all received "standard" physiotherapy and occupational therapy treatment, which was based on the Bobath Approach. Central to treatment based on the Bobath Approach is the manual handling of the patient by the therapist (Davies, 1985). Subsequently treatment based on the Bobath Approach is therapist led, and the patient is a passive recipient of the treatment (Lennon, 1996). During the study, it was observed that the communication between the therapists and nursing staff was high, occurring frequently and involving comprehensive discussion of patients' abilities. The therapists adopted an educational role, encouraging the incorporation of the principles of the Bobath approach into the nursing care of the patients. Consequently, with regards to the functional movement of patients, it could be argued that the interaction between patients and staff within the hospital environment primarily placed the patient into a passive role. The active role, necessitating motivation, attention and cognition, required for the process of motor learning, appears to contrast greatly with the passive role encouraged by the Bobath approach. The emphasis of the passive role of the patient within the hospital environment may not have been conducive to the active role necessary to promote optimal motor learning. Whether the incorporation of treatment based on the Motor Learning approach into an environment in which treatment was principally based on the Bobath Approach provided a suitable context for the promotion of optimal motor learning could be questioned.

It was observed that the physiotherapists frequently communicated the aims and objectives of the physiotherapy intervention based on the Bobath approach to the patients. Often by the time patients had achieved one-minute of independent sitting balance and had been recruited into the clinical study, there had been substantial contact between the physiotherapists and the patients. It could be argued that, at the time of recruitment into the study, the patients were familiar with the process of physiotherapy, as indicated by the Bobath approach. Subsequently, the active role encouraged by the regime of independent practice might have opposed the established and accepted views of physiotherapy treatment held by the patients. The aim of this study was to investigate a principle of treatment in which the Bobath and Motor Learning approach contrasted: the independent practice of functional tasks. However, the nature of the contrast between the Bobath and Motor Learning Approach may have indirectly influenced the outcome of this clinical study.

The routine of the hospital ward prescribed that the standard therapy treatments occurred in the morning, followed by lunch and then either a period of rest or volunteer-led social activities before visitors arrived in the afternoon. This routine dictated that the only suitable time in which the practice regime could be carried out was between lunch and visiting time in the afternoon. During the study, it was found that, up until the time of recruitment into the practice group, the patients had generally been assisted into bed by the nursing staff for a rest immediately after lunch. This appeared to have become a routine for many of the patients involved in the practice regime, and this resulted in a high number of absences from the practice regime. Patients often reported that they were tired at this time and requested not to attend the practice regime in order to rest in bed. The apparent necessity and / or desire to rest at this time decreased the attendance of the practice regime and could thus be argued to influence the outcome of this study.

The reasons for the apparent necessity and / or desire to rest during the afternoon may potentially have implications for the treatment of patients with stroke and for future research studies. Observations made during the study period indicated that the rest period during the afternoon might have become habitual for patients and nursing staff. However regular comments given by the patients in the practice group during the study period indicated that patients attributed their desire to rest during the afternoon to three main factors. These three factors were related to tiredness arising from the relatively long standard physiotherapy treatment session attended immediately before lunch; to the consumption of a relatively large meal (the routine of the hospital being to provide the main meal of the day at midday); and to a lack of sleep during the night due to the noisy ward environment. The absences from the practice regime, resulting from patient tiredness, led to the speculation that the hospital and ward routine was not conducive to the addition of a regime of independent practice. It could be argued that in order to identify the optimal pattern of activity that would promote recovery following stroke, exploration of the hospital and ward routine and patient activity levels should be carried out.

During the time of the clinical study it was observed that attendance at the practice regime by the patients was often considered by the nursing staff and patients to be "additional", or optional. In contrast, attendance at the standard physiotherapy sessions was generally viewed as a compulsory part of the daily routine. Patients who requested not to attend the standard physiotherapy sessions, but who were medically well enough to do so, were actively encouraged, and often persuaded, to attend by nursing, therapy and medical staff. The process of the clinical trial necessitated the full explanation of the study background and aims, and provision of informed consent by the patient. In order to meet with guidelines for ethical approval, each patient who was requested to volunteer for the trial was informed that involvement in the trial was optional and that they could withdraw from the trial at any time without having to give a reason. Additionally, in the explanation of the study background, the information sheet that was provided to each subject (Appendix H) stated that the subject should not expect to notice any direct benefits from taking part in the study. Consequently, it could be argued that the research process involved in undertaking the clinical trial may itself have contributed to a reduction in the attendance of patients at the practice regime. Furthermore, while motivation and active participation are central to optimal motor learning (Schmidt, 1988, 1991; Magill, 1993), the act of explaining the study background may have served to reduce patient motivation thus adversely effecting the motor learning process.

The processes of ethical approval, the provision of information regarding the study aims by the researcher and the informed consent of volunteers are an essential part of any clinical trial. By their nature, clinical trials must generally be incorporated into an existing clinical environment and routine, and control over the environmental context will be limited. Observations made during this study suggest that the processes involved in executing a clinical trial and the environmental context in which this is done could adversely effect the outcome of the study. It is proposed that if the practice regime had been made a more cohesive and accepted feature of the hospital and ward routine, and that the "additional" or optional appearance of the study had been reduced, the attendance at the practice regime may have been greater.

19.3.4 Motor learning and patients with neurological deficits

The previous sections have discussed the lack of change effected by the independent practice on the majority of the outcome variables, referring to the possible limitations in the implementation of optimal motor learning of sitting balance within the hospital environment. More fundamental than whether the practice regime and specified motor tasks were appropriate to gain motor learning relating to sitting balance is the question of whether the patients retained the ability to re-learn motor skills through the process of practice and feedback.

This study did detect a small, but significant, change in the measured outcome of patients in the practice group, providing limited evidence that independent practice effected changes in the motor performance of patients with stroke. This finding is supported by neurophysiological evidence that suggests that motor performance in individuals with neurological damage occur through mechanisms associated with motor learning (Dobkin, 1993; Devor, 1994; Lee and van Donkelaar, 1995; Rosenzweig and Bennett, 1996; Seitz and Freund, 1997). However, the results of this study also highlight that changes in motor performance may not necessarily be obviously beneficial to function. Further research, investigating the effects of practice and feedback based on scientific evidence, is essential to determine the motor learning ability of patients with neurological deficits.

19.4 The outcome variables

It has been identified that there are no global methods of measuring balance (Horak, 1987; Berg, 1989), and that many available methods are aimed at assessing different aspects of balance (Berg et al, 1989; King et al, 1994). There was therefore no one accepted measure of balance that could be used to assess the effect of the independent practice. As a result of this, the outcome variables recorded in this study were developed specifically for the assessment of the independent practice. It must therefore be challenged whether the outcome variables measured were appropriate valid and sensitive assessors of changes occurring as a result of the practice regime. In response to this challenge, it is necessary to explore the outcome variables with reference to the aimed effect of the independent practice.

The selection of the outcome variables with which to assess the effect of the independent practice was determined in relation to the 3 specified aims of the practice (see section 9.2.1):-

1. The maintenance and achievement of appropriate symmetrical alignment in sitting were assessed by measuring the symmetry of weight distribution during quiet

sitting and by measuring the symmetry of weight distribution during quiet sitting immediately following voluntary movement of the COM within the BOS (lateral reaching).

2. The ability to cope with the effects of gravity and make appropriate balance adjustments while sitting were assessed by measuring the symmetry of movement during the functional activities of rising to stand and sitting down. Rising to stand and sitting down both involve coping with the effects of gravity during the movement to or from sitting (Pai et al, 1994), and require appropriate balance reactions during the movement of the COM between two bases of support (Berger et al, 1989a,b; Pai and Rogers, 1990; Carr, 1992; Hughes et al, 1994; Hanke et al, 1995).
3. The control of body alignment during maximal voluntary shifts of the COP was assessed by measuring the weight transference during a maximal lateral reach to either side.

Thus, although there is no accepted method of assessing aspects of sitting balance, it is proposed that the outcome variables used in this study were appropriate to the aims of the intervention and would have been sensitive to any changes in the sitting balance resulting from the practice regime.

19.5 The study design

Having discussed whether the implemented regime of practice had the potential to create changes in sitting balance and whether the recorded outcome variables were appropriate and sensitive to changes in outcome, it is also pertinent to address whether the study design was appropriate to the research questions.

19.5.1 Sample size

This study was designed as an initial, investigative, study and subsequently the number of subjects included in the study was limited. The restricted number of subjects created limitations in the ability to analyse and generalise from the recorded data. The limited number of subjects was further confounded by the number of subjects who were unable to perform tasks and by the number of subjects who were discharged during the study period. Additionally, the large degree of variation between the outcome measures from the hemiplegic subjects reduced the chances of small differences between the control and practice group being detected.

One of the aims of a small-scale study is to identify the sample size that will be necessary to detect changes in future studies. The minimum number of subjects required in each group can be determined, based on the expected variation in the functional ability score (score derived from the combined outcome measures). The equation for identifying the minimum number of subjects in each group, assuming that the size, n, of each group is equal, is (Bland, 1995):-

$$n = (f(\alpha,P) \times (\text{within group SD})^2 \times 2) / (\text{difference to detect})^2$$

The standard deviation of the functional ability score was approximately 3.8. With a probability, P, of 0.80 of identifying a change, and a significance level, α, of 0.05, $f(\alpha,P)$ is 7.9 (Bland, 1995). Thus, the number of subjects can be determined by using these figures and a value for the "difference to detect".

No accepted methodology could be found for defining the value of the "difference to detect". Replacing the "difference to detect" value with a number of different values demonstrates the limitations of the process of determining sample size. For example, detecting a difference of 1 point on the FAS scale would require a minimum of 228 subjects in each group. This would mean that this study only included approximately 6% of the necessary study numbers. However, detecting a difference of 4 points on the FAS scale would only require a minimum of 14 subjects in each group. This study, which included 28 subjects, would therefore have had an adequate sample size.

The aim must be to use a number that would detect a change in ability that would be clinically relevant. It could be argued that an appropriate methodology would be to determine the number of subjects required to detect a specific percentage change in the FAS. To detect a 10% change in the FAS would therefore involve detecting a difference of 2.8 points. Calculating the number of subjects required in each group to detect a 10% (2.8 points) difference:-

$\Longrightarrow$ $n = (7.9 \times 3.8^2 \times 2) / 2.8^2$

$\Longrightarrow$ $n = 29.1$

Thus, to detect a minimum of a 10% difference in the FAS would require a minimum of 29 subjects in each group. Hence, 58 subjects would be required in the study.

However, it could also be argued that the difference to detect should be based on the results obtained from this study. For example, an observable difference was detected, during test week 2, between the median scores of FAS of the control group and practice group who had completed 7 test weeks (Figure 16.4). The difference between the median scores of the control group and practice group during this week was 3.5 points (Table 16.7). Calculating the number of subjects required to detect an observable difference (3.5 points):-

$\Longrightarrow$ $n = (7.9 \times 3.8^2 \times 2) / 3.5^2$

$\Longrightarrow$ $n = 18.6$

Thus, to detect a difference of 3.5 points a minimum of 19 subjects would be required in each group. 38 subjects would therefore be required in the study.

While it is acknowledged that the process of determining the required sample size can readily by manipulated by substituting different numbers, this process is useful for assisting the design of future studies. The finding that 58 subjects should detect changes of 10% of the FAS and that 38 subjects should detect a difference that was observed in this study leads to the proposal that sample sizes of between 38 and 58 subjects would produce clinically relevant results.

19.5.2 Control and intervention group

During this study, blocked randomisation was used to assign the subjects to the control or practice group. Assessing the ratio of subjects in each group with different independent variables illustrated that there were inequalities between the groups. The gender distribution was very uneven, with the practice group comprising only females. There were no associations found between gender and the majority of outcomes for the healthy subjects, and subsequently the inequality between the groups was unlikely to influence the differences between the control and practice group for these variables. However, there was an exception to this and a low, but significant, association was found between gender and the time taken to reach across to the opposite side for the healthy subjects, indicating that the inequality of gender distribution between the groups could have potentially influenced the results of this study.

The ratio of subjects with left and right hemiplegia was approximately equal in the control group, while there was a greater proportion of subjects with left hemiplegia in the practice group. A distinct difference was observed between the functional ability scores of subjects with left and right hemiplegia with the functional ability of subjects with right hemiplegia being greater than that of subjects with left hemiplegia. The uneven distribution of subjects with left and right hemiplegia between the groups could therefore potentially have influenced the results, and the lack of differences between the groups could be related to the predominance of patients with left hemiplegia in the practice group. Kimura (1977) and Haaland et al (1987) found that the motor performance of a novel, abstract, upper limb task was lower for patients with left hemiplegia than right hemiplegia, supporting the finding of this study.

The inequality in the proportion of subjects with different independent variables between the groups could be attributed to the low number of subjects, and with a larger study the probability of inequalities occurring would have been reduced. However, the observed differences between subjects with left and right hemiplegia, and the potential for differences between subjects with different stroke classifications, lead to the question of whether it would have been appropriate to carry out stratified randomisation to prevent uneven distribution. Future studies should consider the use of stratification during the design of the study.

The blocked random assignment of subjects to either a control or intervention group involved no change to the standard therapy provided to patients, and the intervention took the form of additional therapy. Studies reported in the literature are often limited due to the failure of the researchers to define factors relating to "standard" or "conventional" therapy (e.g. Stern et al, 1970; Logigian et al, 1983; Dickstein et al, 1986; Basmajian et al, 1987; Lord and Hall, 1990; Brunham and Snow, 1992; Sunderland et al, 1992). Ethical considerations prevented the use of a control group that received no therapy intervention. It is proposed that the research design adopted in this study was suitable for the investigation of clearly defined interventions and would be appropriate for the investigation of interventions other than independent practice.

19.5.3 External validity

A potential limitation of the study design was the involvement of the researcher in both the implementation of the intervention and the measurements, and the knowledge of the researcher of the groups of the subjects being tested. It could be argued that the expectations of the researcher could have influenced the results of the measurements of functional activity (the "Rosenthal effect"). In order to reduce the potential expectancy effect, standardised procedures were identified and adhered to during all tests. The objective nature of the measurement system limited the ability for the results to be influenced by the researcher. There would have been greater scope for the influence of the expectancy effect during the subjective assessment of functional ability. To remove this effect, the Barthel Index that was routinely collected by the nursing staff was recorded as a measure of functional ability. Although the group of the subjects may have been known by the nurse assessing the Barthel Index, the nursing staff were not involved with the study in any way, were unaware of the aims and objectives of the study, and were not considered to have any expectations pertaining to the clinical trial.

The patients in the practice group received attention from the researcher, and participated in a group practice session. No specific alternative attention was given to the control group. This difference in attention could potentially have influenced the behaviour of the subjects (the "Hawthorne effect"). However, it could be argued that the attention and interaction with other practice group subjects was a realistic effect of independent practice. It was acknowledged that the attention and interaction provided to the practice group subjects could potentially have influenced the study results, and future research should address this issue.

The physiotherapists and occupational therapists providing the standard treatment were not blind to the groups of the patients in the study. The expectations of the physiotherapists treating the patients could therefore have influenced the treatment provided to each patient. The conflict between the Bobath approach, on which the standard treatment provided by the physiotherapists was based, and the independent practice, which the practice group subjects undertook, could be argued to encourage the formation of expectations. It was acknowledged that the expectations of the therapists treating the patients could potentially have resulted in changes to the treatment given to patients and thus influence the study results. The lack of standardisation of treatment and documentation of treatment prevented the specific assessment of the treatment provided to the patients. The limited resources and the environmental context of this study prevented the physiotherapists from being kept blind to the study groups of the patients. However future studies should attempt to reduce the potential influence of the expectations of the physiotherapists providing the standard treatment.

19.5.4 Experimental design

The experimental design adopted for this study was a randomised controlled design. The randomised controlled design is accepted as a methodology for the establishment of causality (Bryman and Cramer, 1990). Within the clinical setting the randomised controlled trial (RCT) is established as a powerful research process for identifying optimal patient care (Begg et al, 1996). The theory of random assignment of subjects to a control or intervention group is that, due to probability, the members of the two groups will end up as similar as possible. However, this study demonstrated that, due to chance, 100% of the male subjects were assigned to the control group. Although this study used a blocked randomisation procedure, where every subject had a 2:1 chance of being assigned to the control group, each subject had an equal probability of being assigned to the control group. Thus, through probability, the members of the control group and practice group groups should have been similar. The probability of obtaining similar members in two groups increases as the sample size increases. The sample size in this study was relatively low (n=28), thus reducing the probability of achieving similar groups. Although it was proposed earlier (section 19.5.2) that stratified randomisation might have provided a suitable methodology for achieving similar groups, there would be a limit to the number of features that could successfully be controlled for. For example, in a study such as this, patient characteristics such as age, gender, side of hemiplegia and stroke classification could all potentially have influenced outcome. It would not have been feasible to stratify the sample according to each of these variables.

All available volunteers from a designated stroke unit were randomised into this trial over a 10-month period. Achieving a larger sample size would therefore have had substantial resource implications, necessitating a longer time period for the trial or a multi-centre trial. For this study, where there was a lack of previous research on which to base the experimental design, the intervention and the measurement techniques, a larger scale study, with the associated resource implications, was not indicated. However, the limitations found during this small scale RCT indicate that the RCT may not be the most appropriate study design when sample sizes are low. Begg et al (1996) stated that reviews of RCT have identified that a large majority of clinical RCTs had too few subjects to permit firm conclusions to be drawn. It must be questioned whether small scale RCTs are appropriate research methodologies, and whether there are suitable alternatives.

Single-subject designs can be useful in the investigation of the clinical effectiveness of a particular intervention on an individual subject (Polgar and Thomas, 1988). The large variations between subjects, and the potential for change to occur without the addition of independent practice, would make the use of a single subject ABAB design inappropriate. However, rather than the blocked randomised design, an alternative study design could involve the instigation of the additional therapy to all the patients within a stroke unit for a stipulated length of time: the intervention phase. During the control phase no additional therapy would be provided. Measures of outcome would be recorded during both the intervention and control phases. This could be described as a longitudinal ABAB design, where the A and B phases are blocks of time, and none of the patients on the stroke unit carry out independent practice during the A phases (control), and all of the patients carry out independent practice during the B phases (phase). Although this study design has disadvantages relating to the possibility of influences from changes other than the intervention, such as changes to the standard treatment provided to patients, the design also has a number of advantages. This study design might prevent the patients in the different groups from feeling "different" as neither would be aware of each other. It would therefore be possible to address issues relating to the environmental context and times in the daily routine in which the independent practice was carried out; and there would be no restrictions relating to the effect on the control group if the independent practice was carried out within the ward. This study design would also remove the need for randomisation procedures and for the consideration of stratified samples. It is proposed that future studies should consider using an ABAB design, rather than the RCT design adopted in this study.

20. Clinical Implications

20.1 Introduction

The aims of this study were to explore the recovery of aspects of balance in patients with stroke, through comparison of patient data with "normative" values, and to investigate the effect of independent practice by patients with recently acquired stroke on the achievement of specified goals. The specific aspects of balance explored, and the aims of the independent practice, were related to the achievement of normal symmetry of weight distribution during posture and movement. This chapter highlights the clinical implications of this study, with specific reference to the assessment and physiotherapy intervention for patients with acute stroke. The direct inferences pertaining to current physiotherapy intervention arising from this study are stated.

20.2 Assessment of patients with acute stroke

20.2.1 Balance and symmetry

An extensive review of the literature identified that the mean symmetry of weight distribution during posture and movement was an appropriate aspect of balance to be investigated during the assessment of patients with acute stroke. This study concluded that there was no change in the mean symmetry of weight distribution during sitting, standing, rising to stand or sitting down, or any change in the magnitude of weight transference during reaching from sitting, during a period of in-patient rehabilitation. The functional ability, as assessed using the Barthel Index, of the patients improved, indicating that there was no relationship between symmetry of weight distribution during posture or movement and functional ability. The lack of relationship between measures of symmetry of weight distribution and functional ability challenges whether the selection of symmetry of weight distribution as a measure of balance was appropriate for this patient group. It was identified in the review of the literature that postural control was the process of the maintenance of balance. Horak (1987) emphasised that the measurement of postural control should consider the "appropriateness and efficiency of movement strategies used to achieve that equilibrium position". Although the measurement of symmetry of weight distribution was identified to be a pertinent aspect of balance, the use of this outcome measure could be argued not to include appropriate assessment of the *strategies* of postural control.

It was identified, from the literature, that the achievement and maintenance of symmetry of weight distribution during posture and movement was a key aim of physiotherapy treatment for patients with acute stroke. This study demonstrated that this was not achieved during physiotherapy treatment, although the functional ability of patients improved. This evidence suggests that the achievement and maintenance of symmetry of weight distribution may not be an appropriate aim of treatment, and that consideration of other aspects of balance and the movement strategies adopted may be necessary in order to determine appropriate aims and measures of outcome following stroke. Further research is required to investigate the association between symmetry of weight distribution during posture and movement and aspects of balance, postural control, and functional ability.

20.2.2 Measurements of outcome following stroke

The Barthel Index is a subjective rating score that is frequently used both in clinical and research environments to assess the functional ability of patients with stroke (Wade and Langton-Hewer, 1987; Turner-Stokes and Turner-Stokes, 1997). This index was routinely assessed and reported within the stroke unit used in this study. Over the 6-week study period the Barthel Index exhibited an upward trend for the majority of the stroke patients. A positive association, with a low correlation, was found to exist between the Barthel Index and the functional ability score (FAS) derived from the objectively measured outcome variables. However, exploration of the trends over time of the individual outcome variables indicated that there were no apparent trends in the outcome variables relating to sitting or reaching. The trends that existed in the outcome variables relating to standing, rising to stand and sitting down were found to be directly associated with the number of subjects who were unable to perform the function, and there was no apparent trend in the outcome variables of the subjects able to perform the function. The lack of trend in the ability of subjects indicates that the overall upward trend in the FAS was due to an increase in the number of subjects able to stand, rise to stand and sit down rather than in improvements in the ability to perform these tasks within the normal range. This indicates that the correlation between the Barthel Index and the FAS only occurs due to the weighting within the FAS of the ability to perform these tasks.

It is essential that questions relating to the validity of the FAS and to the relative weighting of the different outcome variables included are addressed. The evidence from this study suggests that there was no tendency for improvement in the ability of the hemiplegic subjects to perform sitting, standing, rising to stand, sitting down and reaching within the normal range. The aims of physiotherapy are generally for the ability of subjects with hemiplegia to become more like the ability of healthy subjects. This study suggested that these aims, as related to the measured functions, were not met during 6 weeks of physiotherapy following acute stroke. Hence it appears that the Barthel Index score can improve regardless of whether the specific aims of physiotherapy intervention are met. The apparent ability for the Barthel Index score to improve despite no improvement in the achievement of physiotherapy goals indicates that the Barthel Index may not be a suitable tool for the assessment of the aims of physiotherapy. This argument must be viewed in light of the earlier discussion pertaining to the appropriateness of the use of the mean symmetry of weight distribution as a measure of outcome following stroke. It could be propounded that the Barthel Index may be related to measures of balance other than the mean symmetry of weight distribution during posture and movement.

The suggestion that the Barthel Index may not be an appropriate measure of outcome following stroke is supported by Miyai et al (1997), who proposed that the lack of sensitivity in the Barthel Index resulted in non-significant results in studies of functional outcome. Future studies of physiotherapy intervention must consider the association of the Barthel Index to the treatment effect being investigated, and must not assume that this index provides a valid assessment of changes occurring as a result of physiotherapy intervention. It is proposed that it may be appropriate to include other functional measures in the assessment of functional ability in addition to or instead of the Barthel Index

The suggestion that the changes in the FAS and the Barthel Index are due only to changes in functional ability, and not due to any changes in the ability to maintain postures or move within the normal limits, implies that functional ability may not be related to the ability to perform tasks within the normal limits. This suggestion is supported by Nichols et al (1996) who found no correlation between the FIM score and measures of the symmetry of weight distribution or ability to weight shift in sitting. However, several studies contradict these findings, demonstrating relationships between the symmetry of posture and movement and measures of functional ability. Sackley (1990) reported correlations between the symmetry of weight distribution during stance and motor function and activities of daily living, and Sackley (1991) found a significant relationship between the symmetry of weight distribution during stance and the length of hospital admission. Engardt et al (1993) found a strong correlation between the symmetry of weight distribution during rising to stand and sitting down and the functional ability of patients with hemiplegia; and Durward (1994) reported a low correlation between the symmetry of weight distribution during rising to stand and sitting down and clinical gait assessment. Further research is essential to determine whether "normal" posture and movement is related to functional ability after stroke.

Subjective assessments are often the primary measures of outcome used in the clinical setting (Turner-Stokes and Turner-Stokes, 1997). The results of this study suggest that subjective assessments may not be appropriate for the assessment of the achievement of the goals of physiotherapy. It is argued that future research studies should use outcome measures that are accurate and precise, and are directly related to the aims of the study. While subjective assessments could potentially be valuable in the clinical environment, care has to be taken in the generalisation of these assessments. This study has demonstrated that objective measurement systems can be quick and easy to use in the clinical setting and may provide information that is highly relevant to the specific goals of physiotherapy. It is proposed that the clinical measurement system used in this study could be an appropriate objective measurement tool for the routine assessment of patients with stroke in the clinical setting. However, before the measurement system used in this study can legitimately be incorporated into the routine assessment of patients with stroke, further research is required in order to ascertain the appropriateness of measurements of the symmetry of weight distribution to the outcome of patients following stroke.

20.2.3 The clinical measurement system

It has been identified in the literature that patients with acute stroke can present with a wide range of sensori-motor deficits (Wade et al, 1985b). Problems relating to the control of balance have been proposed as common (Knott and Voss, 1968; Brunnstrom, 1970; Bobath, 1978, 1990; Davis, 1985, 1990; Carr and Shepherd, 1989a, 1992; Ashburn, 1997), with problems with balance during specific postures and movement being highlighted by many authors. Despite the apparent acceptance that problems with balance are very common in the patient with acute stroke, there are few assessments described that can provide objective evidence relating to deficits in balance and that are suitable for use in the clinical setting. The objective clinical measurement systems that are available primarily concentrate on the assessment of balance during stance. Although aspects of balance in stance have been identified as problems following acute stroke, it can be argued that tools that are only capable of assessment of balance during one posture are of limited use in the clinical setting. The measurement system used in this study was designed to be suitable for use in the clinical setting and to provide accurate and precise objective assessment of aspects of balance in a number of different postures and movements in patients with acute stroke.

A series of calibration checks were carried out to determine the accuracy and precision of the measurement system used in this study. These checks demonstrated that the measurement system had a high degree of accuracy and precision.

The measurement system used in this study had previously been used in a clinical setting (Durward, 1994). However, all the patients involved in the clinical study carried out by Durward (1994) had the ability to ambulate, either independently or with assistance, and to mobilise on to the platform and into the chair. The physical dysfunction of the patients involved in this study was greater than in the study by Durward and, at entry into the study, none of the patients had the ability to walk, with or without assistance. Subsequently the patients had to be assisted to transfer from a wheelchair into the measurement chair. Due to the height of the measurement platform, the wheelchair had to be manoeuvred on to a second platform adjacent to the measurement system in order to allow the transfer to take place. While this system was satisfactory for the duration of the study period, a permanent extension to the measurement platform, including a wheelchair ramp, would assist in the ease of use of this system within the clinical setting. In addition, the incorporation of an extended platform with ramp might make the use of a mechanical hoist possible to transfer heavy or more severely disabled patients. Patients requiring to be transferred with a hoist could not be included in this study.

During the assessment of standing, rising to stand and sitting down of some of the more disabled patients the tester required an assistant to ensure patient safety. The necessity for the tester to return to the computer in order to initiate a new test at times placed limitations on the testing procedure as the patient was unable to remain standing independently during this process. Although recording could be started with the hand-held switch, the ability to operate more functions with a hand-held switch would have been beneficial to the use of the system in the clinical setting.

For one subject in the clinical trial, tests of standing, rising to stand and sitting down could not be assessed. This subject was able to achieve these tasks, but was unable to maintain his feet on the foot measuring sections during these tasks. Other subjects required prompting or repeated tests to ensure that the feet were kept on the measurement sections during the tests. Larger force measuring sections within the platform of the measurement system might assist in the ability to assess standing, rising to stand and sitting down with this patient group.

However, in general, the measurement system was found to be suitable for use in the clinical setting and for use with patients with severe physical disabilities. It is proposed that this measurement system could be useful for future clinical research studies and also for routine use by physiotherapists to attain objective measures of patient outcome that are specific to the goals of treatment.

20.2.4 Data presentation and clinical assessment

The symmetry and time variables derived from the measurements in this study were ratio data. However, during the analysis of data a procedure was utilised to convert the ratio data into ordinal data. The categories of "normal", "abnormal" and "unable" were defined, based in the results of data from healthy subjects. The patient data was then categorised as "normal", "abnormal" or "unable" for each task assessed.

The conversion of ratio data into ordinal data is not a process that is commonly found described in the literature for the assessment of function. Hamrin et al (1982) presented data that had been converted in a similar manner. Hamrin et al (1982) assigned a ranked score (1, 2 or 3) to ratio data collected from a force platform during a test of standing balance. In the review of the literature, the data presentation used by Hamrin et al (1982) was criticised, as the method of assigning ranked scores was not explained and the presentation lost the advantages of the sensitivity of the ratio data. The only explanation of the assignment of ranked scores was:

> "with the help of the recording the standing balance was estimated, using a maximum score of 3 (normal or nearly normal balance)."

No further definitions were provided. Although the use of ranked data, rather than ordinal data, could be challenged, with a clear and concise definition of the method of converting the ratio data based on accepted statistical processes, it could be argued that the conversion of ratio data to ordinal data could be a statistically valid procedure. This process of analysis was found to be extremely valuable in this study, resulting in unequivocal presentation of data and providing data suitable for statistical analysis (using the Chi-squared test).

A common aim of physiotherapy treatment is to return a patient to having "normal" movement. "Normal", although rarely defined, generally refers to movement that is within the limits of movement carried out by the healthy population. The presentation of ratio data can be extremely informative, providing details pertaining to the quality of movement and allowing changes within and between subjects to be identified. However, interpretation of ratio data could be argued to be more difficult than the interpretation of simple, clearly defined, ordinal data. A physiotherapist presented with a symmetry index value would have to make a judgement regarding the meaning of the value to a patient's ability. In contrast, the classification of a patient's ability as "normal", "abnormal" or "unable" would be unequivocal and have direct relevance to the goals of physiotherapy.

The presentation of ordinal data does have a number of disadvantages, such as the lack of ability to detect small changes in patient ability, and ratio data has an important and irreplaceable role in the assessment of patient ability. However, it is argued that the conversion of ratio data to ordinal data can be advantageous, providing objective data that has high clinical relevance and that is easy to interpret.

20.3 Physiotherapy for patients with acute stroke

20.3.1 Independent practice as an addition to physiotherapy intervention

This study found that there were no benefits relating to the addition of a regime of independent practice to physiotherapy intervention based on the Bobath approach. No evidence can therefore be proposed for any change to current clinical practice. It has been proposed that the independent practice, based on the motor learning theories, had a number of limitations that prevented the promotion of optimal motor learning. Problems and limitations relating to the independent practice have been discussed in section 19.2. It has been identified that the practice regime did not meet with all the criteria for optimal motor learning and that the number of repetitions and practice sessions may have been inadequate. Thus, although it has been demonstrated that the independent practice carried out by patients in this study was ineffectual at aiding recovery, this study is unable to conclude that the Motor Learning approach is ineffectual if appropriately applied.

In order to increase the methodological rigour of this study, the intervention (independent practice) was highly standardised. The clinical relevance of the application of a standardised regime of practice, with no direct physiotherapy supervision, must be challenged. The Motor Learning approach emphasises that individual tasks should be assessed and evaluated; problems identified and missing components practised (Carr and Shepherd, 1989b, 1990, 1992). The use of the standardised practice regime in this study prevented the incorporation of assessment and identification of problems for individual patients. In addition, the Motor Learning approach advocates continuous assessment of the motor performance of individual patients so that the practice of tasks can be progressed as motor performance improves. While the practice regime used in this study included progression relating to the distance and height of reaching, the use of the standardised practice regime prohibited assessment and subsequent progression of the motor tasks performed by individual patients. Thus, although in terms of study design and methodological rigour the application of a standardised practice regime to the entire study population was advantageous, it must be challenged whether the standardisation was clinically appropriate.

Although it was identified from the literature that the Bobath approach and the Motor Learning approach differed in respect of the support for independent practice, the degree to which the practice promoted by the Motor Learning approach is truly "independent" may be debated. If patients practice tasks, without the continuous physical guidance advocated by the Bobath approach, but with physiotherapeutic supervision, the provision of feedback and the continuous progression of motor tasks, can the practice truly be described as "independent"? The theories pertaining to the optimal acquisition of motor skills, on which the Motor Learning approach is based, do highlight the importance of feedback and providing the learner with the "idea" of the movement to be achieved. Whether the use of "independent" practice as adopted in this study successfully fulfilled the aims of clinical practice as advocated by the Motor Learning approach must be challenged.

During this study the intervention (independent practice) was administered as an addition to the "standard" physiotherapy treatment that patients received. The standard physiotherapy treatment was based on the Bobath approach. It has been proposed (section 19.3.3) that the provision of the independent practice as an *addition* to the treatment based on the Bobath approach, may not have been a suitable methodology for the investigation of the effect of independent practice. If, as previously suggested, the nature of the contrast between the Bobath and Motor Learning approaches result in incompatible treatment strategies the legitimacy of physiotherapists adopting a combination of treatment techniques may be challenged. Further investigation to determine the effect of administering treatment based on one approach as an "addition" to treatment based on another approach is required.

20.3.2 Physiotherapy and the achievement of "normal" posture and movement

Regardless of the approach to physiotherapy, the aims of treatment are generally for patients to return to having "normal" posture and movement. The failure for this goal to be achieved, as found in this study, challenges whether this is a realistic goal of treatment. Although neurophysiological theories of recovery and plastic changes following neurological damage suggest that structural reorganisation of the CNS can occur (Dombovy and Bach-y-Rita, 1988; Dombovy, 1991; Devor, 1994; Good, 1994; Illis, 1994), the degree to which the functioning of the individual can beneficially change remains unknown (Bach-y-Rita, 1981b; Dombovy and Bach-y-Rita, 1988; Dombovy, 1991). Thus, although neurophysiological evidence exists that changes in functional ability can occur despite damage to areas within the CNS, whether the changes in functional ability will be sufficient to return the individual to entirely "normal" functioning has not been established. This study demonstrated that patients with neurological damage gained the ability to perform certain functions over time, but that there was no change in the ability to perform those functions within the "normal" range. This suggests that while plastic changes may act to enable patients to carry out functional activities, this process appears to involve adaptation that allows the function to be carried out, but not necessarily within the "normal" range. If it is not possible, due to the neurophysiological mechanisms of recovery, for patients with stroke to regain "normal" posture and movement, this implies that the current aims of physiotherapy intervention are unachievable. In contrast, if the neurophysiological mechanisms of recovery can occur to the extent of allowing patients with stroke to regain "normal" posture and movement, this implies that the current physiotherapy interventions are ineffectual at obtaining these goals.

Durward (1994) also concluded that the aims of achieving normal movement and posture following stroke were not achieved, and proposed that this could be due to intrinsic factors relating to patient motivation. Durward (1994) proposed that

> "it is possible that patients adopt a pragmatic approach to recovery and are less concerned with the 'nuances' of motor performance such as symmetry. This underlying attitude may account for the lack of change in performance."

The proposal by Durward suggests that the failure of the physiotherapy intervention is due to a lack of motivation on the part of the stroke patients to attain "normal" movement. This implies that physiotherapists must not only consider whether the goal of "normal" movement is realistic in terms of the neurophysiological mechanisms involved but also whether the goal of "normal" movement is meaningful and desirable to the patient. DeSouza (1983) also questioned whether physiotherapists provided goals which motivated patients with stroke. It may be that the attainment of "normal" posture and movement is not meaningful or important to an individual following stroke: the achievement of "optimal" posture and movement, taking into account the specific neurological damage and sensori-motor dysfunction of that individual may be a more appropriate, relevant and meaningful goal.

The lack of achievement of "normal" movement can lead to the proposal that the aim of achieving "normal" posture and movement may be inappropriate. The goal of achieving normal patterns of posture and movement is central to the Bobath approach (Davis, 1985; Bobath, 1990). Thus the suggestion that the aim of achieving "normal" posture and movement is inappropriate challenges the fundamental basis of treatment based on the Bobath approach. Conversely, if the aim of achieving "normal" posture and movement is assumed to be an appropriate goal, the lack of change demonstrated in this study challenges the effectiveness of treatment based on the Bobath approach. Hence, regardless of the appropriateness of the goal of achieving normal posture and movement, the results of this study dispute whether the Bobath approach to physiotherapy is effectual in the treatment of patients with stroke. This contention highlights the necessity for investigation of the efficacy of the Bobath approach, which is – in turn – reliant on the provision of adequate up-to-date written material pertaining to the approach.

20.3.3 The efficacy of current physiotherapy intervention

Assuming that the achievement of normal symmetry of posture and movement was an appropriate goal, then the results of this study imply that the current physiotherapeutic interventions may not be efficacious at achieving this goal. Thus the results of this study imply that physiotherapy for patients with stroke may not promote optimal recovery. The available neurophysiological evidence indicates that functional recovery following neurological damage occurs through plastic mechanisms involving the same processes as learning new motor skills (Dobkin, 1993; Devor, 1994; Lee and van Donkelaar, 1995; Rosenzweig and Bennett, 1996; Seitz and Freund, 1997). Although there are a number of different physiotherapy approaches for the treatment of patients following stroke, it has been identified that the evidence given in support of the different approaches is often the same (Lennon, 1996). At present there is substantial evidence that suggests that no one treatment approach is more beneficial that the other treatment approaches (Stern et al, 1970; Logigian et al, 1983; Dickstein et al, 1986; Lord and Hall, 1986; Basmajian et al, 1987; Ernst, 1990; Wagenaar et al, 1990; Gelber et al, 1995). The results of this study are unable to refute this evidence and, in addition, this study is unable to demonstrate any specific benefits of either of the physiotherapy approaches investigated in the achievement of the goal of "normal" weight distribution during posture and movement. It is imperative for the provision of treatment able to promote optimal recovery that physiotherapy intervention incorporates all the available scientific knowledge and relates this to both the aims and the practice of physiotherapy.

20.4 Direct inferences of study results to clinical practice

The results of this study have led to discussion and comment relating to the assessment and treatment of patients with acute stroke. The extent to which the results of this study directly indicate and support changes to current clinical practice must be highlighted.

This study found that the addition of a regime of independent practice, aimed at improving sitting balance, to standard physiotherapy intervention resulted in no observed or measured changes in patient performance or outcome. Thus the results of this study do not support the independent practice of motor tasks as an addition to standard physiotherapy intervention by patients with stroke. No direct inferences can be made from the results of this study relating to the physiotherapy treatment given to patients with recently acquired stroke

Measurements of the symmetry of weight distribution during sitting, standing, rising to stand and sitting down and the weight transference during reaching from sitting indicated that there was no change in these parameters during the study period. The relatively low number of subjects in the study, the variation between subjects, and the failure to continue to collect data from patients discharged home during the study period limit the ability to generalise from the results of this study to the wider population of patients with recently acquired stroke. In addition, it must be recognised that the results of this study were limited to the measurement of the mean symmetry of weight distribution during specified postures and movements. There is no direct evidence that the measures of symmetry relate to alternative measures of balance or postural control, or that measures of symmetry are sensitive to the changes in the motor performance of patients with stroke. Thus the measurements of symmetry of weight distribution recorded during this study have no direct impact on clinical practice.

The results of this study can be argued to have direct implications for future research. Several methodological issues pertaining to study design, to the measurement of balance and symmetry, and to data presentation and clinical assessment, have been highlighted during this study. However, no inferences pertaining directly to clinical practice can be procured from this study.

21. Suggestions for further research

This study has identified copious areas requiring further scientific exploration, and has been argued to have direct implications for future research. The following sections highlight some of the key areas of further research arising directly from this preliminary study.

21.1 Studies of functional abliity

The measurement system developed and used in this study was used to investigate symmetry during a number of postures and movements, and asymmetry during reaching from sitting. The system provides information pertaining to the vertical forces passing through different body parts. There is potentially valuable information to be derived from the exploration of the vertical forces through each of the 10 force measuring sections, and from the investigation of the relative symmetry within the feet and seat during posture and functional movement.

The literature review identified that there were many methods available for the assessment of different aspects of balance. There is a lack of evidence pertaining to the relationship of the various measures of balance. Future studies to investigate the relationship between different measures of balance will be useful to identify the appropriateness of different outcome measures in the assessment of human balance. This could include the investigation of the association between measures of the symmetry of weight distribution and measures of the position of the COP. In addition to the investigation of different methods of measuring balance, there is also a necessity to identify the relationship, if any, between different outcome variables; for example, the different variables that can be derived from the measurement of the movement of the COP.

In this study, a number of different outcome variables were used in the description of the functional ability of patients with stroke. There is a need for further investigations of the relationship between the different symmetry and time variables during different functions, and the relative weighting of these variables in the construction of the total functional ability score used in this study. Such investigation could lead to the creation of a battery of outcome measures that could be used to validly express balance in the clinical situation or during further research studies. Studies of the balance ability of patients with stroke could determine whether the nature of balance deficits following stroke are related to variables such as the side of hemiplegia or the stroke classification.

21.2 Studies of functional recovery following stroke

This study identified that there was generally no change in the ability of patients with stroke to achieve "normal" posture and movement, over a period of 6 weeks. Longitudinal studies, with larger sample sizes, to confirm the finding of this study and to assess if the lack of change is maintained over longer periods of time, are essential to determine whether and to what extent the current aims of physiotherapy are being achieved. Additionally, exploration to assess the association of alternative measures of functional outcome with measures of symmetry and time of movement will allow the investigation of the relative importance of "normal" movement to outcome following stroke.

Further objective assessments of the sensori-motor dysfunction relating to balance following stroke, using methods other than that used in this study, are important to accurately identify problems following stroke and, subsequently, relevant aims of treatment. This study concentrated on the measurement of kinetic data; it is proposed that measurements of the kinematic features of posture and movement will provide valuable data relating the symmetry of weight distribution to the symmetry of posture and movement. Studies investigating the kinematic features of functional activities could also provide objective evidence pertaining to the appropriateness of specific motor tasks for independent practice aimed at achieving specific changes in motor performance. Studies of the relationship of the recovery of different functional tasks should be carried out in order to address issues relating to the specificity and transferability of functional ability.

21.3 Studies of physiotherapy for stroke

This study has identified that further studies of the efficacy of physiotherapy and the relative efficacy of different approaches to physiotherapy are essential in order to identify the optimal treatment for patients with stroke. The review of the studies in the literature that have compared the efficacy of different treatment approaches emphasises the necessity that future studies should ensure that the treatment approaches investigated are based on written scientific evidence or hypotheses. This study has identified that there are many problems associated with the definition of treatment approaches. It is proposed the future investigations of treatment for patients with stroke should consider the use of the study design adopted in this research study, involving the use of an "additional" treatment.

This initial study investigated the effect of independent practice as an addition to normal physiotherapy input. The results of this study support the implementation of further studies to investigate independent practice based on the principles of motor learning. However, this study led to the conclusion that the practice regime implemented in this study did not encourage optimal motor learning. It is proposed that the practice regime needs to be revised, in light of the evidence obtained during this study pertaining to factors such as the timing and number of repetitions and subject motivation, and a further study carried out. The implementation of further studies to ensure that the practice regime is appropriate both in its aims and methods are recommended as essential before considerable resources are used in the execution of a large scale study. This study indicated that sample sizes of up to 58 subjects may be required for a full scale study. In addition to reviewing the regime of independent practice, it has been proposed that an alternative study design could be a longitudinal ABAB design. This study produces evidence that indicates that such a research design may have considerable advantages in the ability to provide opportunities for independent practice that promote optimal motor learning and recovery. A study to investigate the use of this experimental design in the investigation the effect of independent practice is indicated.

22. Conclusions

The aims and objectives outlined in the rationale for this study (sections 6.2 and 6.3) have been met.

- The measurement system was found to be accurate, precise and suitable for use in the clinical setting. The measurement system provided objective measures of the symmetry of weight distribution during sitting, standing, rising to stand and sitting down, and of the weight transference during lateral reaching from sitting.

- The symmetry of weight distribution during sitting, standing, rising to stand and sitting down, and of the weight transference during lateral reaching were found to be highly relevant objective measurements of the specific aims of physiotherapy for patients with recently acquired stroke. Classification of the objective ratio data into ordinal data ("normal", "abnormal", "unable") was found to be advantageous, providing unequivocal data that was easy to interpret and had high clinical relevance. This study highlighted the benefits of objective measures of physiotherapy goals, as compared to more global, subjective, assessors of functional ability, such as the Barthel Index.

- A regime of practice aimed at the restoration of sitting balance was developed, based on the available literature. The efficacy of the régime has been discussed, based on the study results, and methods of improving the regime of independent practice, in future studies, proposed.

- A randomised clinical trial was carried out to investigate the recovery of the symmetry of weight distribution during different postures and movements in patients receiving standard physiotherapy (based on the Bobath approach) and in patients receiving standard physiotherapy plus an additional regime of practice (based on the Motor Learning approach). The experimental design adopted for this study was found to be appropriate and valid for use in the investigation of independent practice as an addition to standard physiotherapy in the clinical environment. However, this study identified several pertinent points pertaining to the use of the randomised controlled design, such as the effect of the environmental context and the potential for uneven groups despite randomisation. It has been proposed that a longitudinal ABAB study may be more advantageous than small-scale randomised controlled trials for future research studies.

With reference to the hypotheses outlined in section 6.4, the following conclusions were made:-

22.1.1 Healthy subjects

A. Young and elderly healthy subjects demonstrated symmetrical weight distribution during sitting, standing, rising to stand, and sitting down.

B. Young and elderly healthy subjects demonstrated a consistent pattern of weight transference during reaching out to the side from a sitting position.

C. There were few relationships between the age, weight, height or gender of the healthy subjects with the objective measurements of symmetry of weight distribution and time during sitting, standing, rising to stand, and sitting down, and weight transference during reaching out to the side from a sitting position. The exceptions to this were significant relationships between dominant hand and the symmetry of weight distribution during the seat-on phase of sitting down; between age and the time taken to reach to the same side; and between gender and the time taken to reach across to the opposite side.

22.1.2 Subjects with recently acquired stroke

D. The symmetry of weight distribution during sitting, standing, rising to stand, and sitting down, and the weight transference during reaching out to the side from a sitting position, of subjects with recently acquired stroke was different from that of young and elderly healthy subjects. Hemiplegic subjects tended to distribute more weight to the unaffected side than to the affected side during all "symmetrical" postures and movements. This tendency was greater during standing and the seat-off phases of rising to stand and sitting down than during sitting and the seat-on phases of rising to stand and sitting down. The weight transference during reaching of hemiplegic subjects was less than that of the healthy subjects.

E. The symmetry of weight distribution during sitting, standing, rising to stand, and sitting down, and the weight transference during reaching out to the side from a sitting position, of subjects with recently acquired stroke did not approach that of young and elderly healthy subjects, over a period of 7 weeks during which standard physiotherapy (based on the Bobath concept) was administered. This study concluded that there was no change in the symmetry of posture and movement, or ability to transfer weight, in patients with acute stroke who received 6 weeks of in-patient physiotherapy treatment. It was proposed that either the aims of physiotherapy were inappropriate and unachievable or that the physiotherapy intervention was ineffectual at achieving the aims of treatment. This finding, if confirmed, has fundamental implications for physiotherapy aims and treatments.

F. There were few relationships between the symmetry of weight distribution during sitting, standing, rising to stand, and sitting down, and the weight transference during reaching out to the side from a sitting position in individual patients with recently acquired stroke. The exceptions to this were significant relationships between the symmetry of weight distribution during stance and during the seat-off phase of sitting down; and between the time taken to reach to the unaffected side and to reach to the affected side.

G. There was a very weak relationship between the functional recovery, as assessed using the Barthel index, of patients with recently acquired stroke and the symmetry of weight distribution during sitting, standing, rising to stand, and sitting down, and the weight transference during reaching out to the side from a sitting position. This relationship appeared to be due to the increase in the number of subjects able to stand, rise to stand and sit down, rather than to an increase in the ability of subjects to perform the functions within a normal range.

22.1.3 Effect of regime of practice aimed at improving sitting balance

H. Patients with recently acquired stroke receiving standard physiotherapy (based on the Bobath concept) plus an additional regime of practice (based on the motor learning approach) aimed at improving sitting balance had no greater recovery of symmetry of weight distribution during sitting, standing, rising to stand and sitting down, and weight transference during reaching out to the side from a sitting position than patients with recently acquired stroke receiving standard physiotherapy (based on the Bobath concept). The only differences between the patients receiving and not receiving the additional regime of practice was that patients receiving the practice distributed more weight through the affected side during sitting after reaching than the patients not receiving the practice. The consequence of this change in motor performance was not known. These conclusions led to the proposal that the lack of effect attributable to the practice regime occurred as the practice regime did not promote optimal motor learning. However, it was proposed that the small differences in the outcome variables of the control and practice group indicated that the independent practice could potentially effect a change in motor performance.

I. The difference in the symmetry of weight distribution during sitting following reaching between patients with recently acquired stroke receiving standard physiotherapy (based on the Bobath concept) plus an additional regime of practice (based on the motor learning approach) and patients with recently acquired stroke receiving standard physiotherapy (based on the Bobath concept) was not maintained during tests of retention for up to 2 weeks following the cessation of the additional regime of practice. This indicates that no motor learning occurred.

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Appendix A : The Barthel Index

Activity	Score	Criteria
Feeding	2	Independent
	1	Needs help
	0	Dependent
Grooming	1	Independent
	0	Dependent
Bowels	2	Fully continent
	1	Occasional accident
	0	Incontinent
Bladder	2	Fully continent
	1	Occasional accident
	0	Incontinent
Dressing	2	Independent
	1	Needs help
	0	Dependent
Chair/bed transfer	3	Independent
	2	Minimum help
	1	Able to sit
	0	Dependent
Toilet	2	Independent
	1	Needs help
	0	Dependent
Mobility	3	Independent walking
	2	Minimal help
	1	Independent in wheelchair
	0	Immobile
Stairs	2	Independent
	1	Needs help
	0	Dependent
Bathing	1	Independent
	0	Dependent

Assessment of the Barthel Index gives a score from 0 to 20, inclusive.

Appendix B : Details of measurement equipment

Backrest switch

Low profile pressure switch (Radiospares 317-156). Triggered by forces greater than 14N.

Seat and foot force measuring sections

Each individual load measuring quadrant comprised four micro-measurement foil strain gauges, with gauge lengths of 1.57mm (EA-06-062 AA – 120), and connected to a full bridge configuration to ensure that the vertical component of the load on the loading surface was measured independently of the application point.

Strain gauge amplifiers

Commercially available units – Fylde FE-359-TA bridge/transducer amplifiers.
10 amplifiers were used; 4 for the seat sections, 4 for the foot sections, 2 for the arm rests.
The gain settings on each amplifier were individually adjusted to establish an output of 4 computer units for every 1N of force.

Analogue to digital converter

Multi-channel external analogue to digital converter; 8 channel, 12 bit, system giving resolution of 4096 units in each channel.

A full description of the measurement system is reported by Durward (1994).

Appendix C : Investigations carried out during the development of the regime of practice

1. Investigation of height, angle, and distance of reach

Investigation	(A1)1
Aim	Preliminary exploration of parameters of height, angle and distance or reach.
Method	Subject sitting on plinth. Table placed in front of subject. Table height adjusted to get set amount of shoulder flexion (30°, 60°, 90° or 120°) from subject, when hand placed on edge of table with 0° shoulder abduction and 0° elbow extension. Bean bags placed at 0, 10, 20, 30, 40, 50, 60, and 70cm from midpoint of front edge of table; at angles of shoulder abduction of 0°, 30°, 60°, 90°, 120°, 140°, -30° and -60°. Subject asked to bring bean-bags back to centre at selection of different heights(shoulder flexion) and angles (shoulder abduction) from linearly increasing distances away from the midpoint.
Results + discussion	• Subjects leaning heavily on the table with unaffected arm - this is altering the type of postural control being used. i.e. the subjects are using musculature around the arm and shoulder girdle, in preference to the use of the trunk musculature. • Repeated reaching in the same direction (i.e. angle of shoulder abduction) resulted in subjects fixing their trunk in a rotated position, and executing the task through use of arm and shoulder girdle movements.
Conclusions	• Tasks that discourage leaning on the table are required. • Repeated tasks at the same angle increased asymmetry - need to assess effects of tasks which necessitate crossing the midline.

Investigation	(A1a)1
Aim	To further investigate the effects of crossing the midline and the differences between reaching from the midline out or from a distance back to the midline.
Method	Subject sitting on plinth. Table placed in front with lines drawn from mid-point at front at -90° to +90° at 30° intervals (where negative values represent lines to the left of the mid-line) - "radial gridlines". Subject to move beanbags from mid-point out along stipulated lines as far as possible, in set order.
Results + discussion	• Subjects appeared to be more aware of returning to the "middle" through use of the midpoint of the radial gridlines. • Subjects continuing to lean on table with unaffected arm. • Repeated tasks to the same side resulted in the maintenance of a rotated posture to that side. • Subjects were able to rotate around and reach across their body to 90° without excessive difficulty (i.e. reach to affected side with unaffected arm).
Conclusions	• Radial gridline provides a good visual representation of midline. • Tasks that discourage leaning on the table are required. • Must avoid repetitive tasks to the same side. • Tasks at 90° get good rotation.

Investigation	(A1b)2
Aims	a) To further investigate the effects of crossing the midline, without repetitive movements to the same side. b) To compare the effects of undertaking tasks at table height and above table height.
Method	Subject sitting on plinth. Table placed in front of subject with a series of lines across table at 20cm intervals - "tramlines". Two blocks with rope between were able to be place at either end of a line to create a "raised" line, 10cm above the height of the table. Subject to either move blocks out along lines, or pegs out along rope. As a further exploration; at the end of this investigation, the subject was asked to reach up as high as possible.
Results + discussion	• Despite the rope being 10cm above the table the subjects still leant through the table with their arms, and maintained a flexed posture. • The investigation at the end, when the subject was asked to reach as high as possible, resulted in the subject gaining trunk extension and moving to a midline position in order to maintain an upward reach. • Repetitive movements to the same side resulted in increasing rotation to that side; this was prevented by providing tasks which involved moving through the midline. • If the command to "stop in the middle" was given yet there was no specific task to be performed in this position, then the subject failed to stop in the desired position. Tasks demanding an object to be placed in the middle resulted in the subject stopping the movement in this position. • The subject did not seem to have a very good concept of the "middle" and adopted an asymmetric posture during the majority of the investigation.
Conclusions	• Tasks at only a small height above table still allow the patient to lean through the table - need to investigate the effects of reaching much higher. • Reaching high achieves good trunk extension, as compared to tasks at table height. • Repetitive movements to the same side ought to be avoided. • Unless exercise specifically requires stopping in the midline, instructions to "pause" in midline are not sufficient. • Use of tramline set up did not give a good visual representation of midline.

Investigation	(A1c)3
Aim	To investigate the height of reaching.
Method	Subject sitting on plinth. Table placed in front of subject with a series of raised strings in a triangular formation (see exercise sheet A1c in Appendix). Strings were at a height of 10, 35, and 60cm above the table. Subject to perform a series of tasks involving moving and placing pegs on various points on the strings (see exercise sheet A1c in Appendix).
Results + discussion	• This set up avoided the subject leaning through the table, this reduced the subject's ability to "fixate" with the arm and shoulder girdle and thus necessitated an apparently greater degree of trunk control • The subject did not appear to require much trunk movement in order to reach straight up above head and back to table height - this movement could be performed with the trunk fixed in a flexed position and using arm and shoulder girdle movements. • Moving to and away from a "high" midpoint resulted in greater trunk extension, as compared to moving to and away from a midpoint at table height.
Conclusions	• Heights challenge balance, and require greater postural control. • Moving in the midline did not challenge balance. • Moving objects to / from a high midline position achieves greater trunk extension.

Investigation	(A1d)4
Aim	a) To further investigate the height of reaching, to the sides. b) To investigate the use of a barrier at the edge of the table. c) To investigate the use of different tasks.
Method	Subject sitting on plinth. Table placed in front of subject; radial gridlines drawn on table. Vertical boards placed in arc at 85cm from midpoint. A 10cm "barrier" was placed along the edge of the table in an attempt to prevent the subject leaning through the table. Task 1 - drawing lines on vertical boards. Task 2 - moving and stacking cones on radial gridlines. Task 3 - drawing lines around points on radial gridlines.
Results + discussion	• Vertical boards too far away from midline to allow subject to achieve any height. • Moving one cone out as far as possible, and placing a second cone on top required the subject to maintain the distance of their maximum reach in a controlled manner. This required maintained postural control. • The subject leant on the barrier, if prevented from leaning on the table.
Conclusions	• Horizontal distance of reach needs to be reduced to allow vertical height of reach to be suitably challenged. • Stacking tasks are successful in obtaining controlled, maintained reach, without leaning through table. • Barrier not suitable for preventing subject leaning through table.

Investigation	(A1dii)5
Aim	a) To further investigate the height of reaching, to the sides. b) To investigate the use of different tasks.
Method	As Investigation (A1d)4, but with the horizontal distance to the vertical board reduced to distances of 50 - 70cm (as dictated by distances achieved in previous investigations).
Results + discussion	• Drawing tasks require complex instructions, and do not provide a concrete goal for the task.
Conclusions	• Reduced horizontal distance more suitable. • Drawing tasks do not provide concrete goal.

2. Investigation of Seating

Investigation	(A2)
Aim	To investigate the effects of the subject sitting:- a) on a plinth; b) on a standard chair, with straight back and wooden arms; c) in his or her own wheelchair.
Method	A number of the exercises from investigations (A1) and (A3) were repeated with subjects sitting in 2 or 3 of the above sitting positions.
Results + discussion	a) The plinth provides no support and necessitates a great degree of postural control at all times. The subject generally feels least secure in this sitting position. The subject is unable to have a rest at any time, as there is no available support. This is potentially the least safe sitting position to leave a subject in to undertake "independent" practice. b) A standard chair (seat width 0.48m, depth 0.42m) did allow the subject to lean backwards and have some trunk support. However, during the exercises the subjects moved forwards away from the back support, and maintained similar postures to those achieved on plinth. During reaching out to the sides subjects occasionally leant through the arm rests, however this was avoided when exercises involving "height" were executed. c) The wheelchair placed the subject in a position of trunk flexion, from which they found it difficult to come forwards. The support given by the wheelchair prevented the movement that was obtained in the above sitting positions. The arms of the wheelchair were

	restrictive, and subjects were able to lean their trunks against the arm rests even during exercises involving "height". Removing the arms of the wheelchair reduced the safety of this sitting position, and made subjects frightened to reach out to the sides.
Conclusions	• The wheelchair is unsuitable due to the posture it places the subject in, and the degree to which it restricts movement by the subject. • The plinth provides least safety for the subject, and is reported by the subjects to be the most frightening sitting position to be left in. • The standard chair provides a safe environment for the subject, without placing too many restrictions on movement. A standard chair is also more available in many environments than wheelchairs or plinths. • **Subjects will sit in a standard upright chair during the practice regime.**

3. Investigation of Effects of Targeting

Investigation	**(A3)**
Aim	To investigate the effects of targeting and scoring on subject motivation and achievement.
Method	Subject sitting in standard chair. Table placed in front with variety of radial gridlines drawn on:- a) plain lines b) colour-coded lines c) scored lines. The subject was asked to move a cone out as far as possible at along lines at angles of -90°, 90°, -75°, 75°, -60°, 60°, -45°, 45°, -30°, 30, -15°, and 15°, and then place a second cone on top of the first. This was repeated with each of the 3 varieties of gridines. The distance that the subject achieved on each task was recorded.
Results + discussion	• Subjects tended to be more motivated on second and further attempts in that they attempted to "beat" their first distance. • Colour coded lines did not appear to improve motivation, and did not appear to present such a clear concept of the midpoint. • Scoring appeared to improve motivation, but the 10cm score lines used appeared to be too far apart in that it was not possible to improve by 1 score point.
Conclusions	• Scoring appears to improve motivation and should be incorporated into the practice regime. • Scores would have to be sensitive to small improvements. • Use of distance measurements as distance indicators should be investigated in the final stages of development.

4. Investigation of Different Tasks

Investigation	**(A4)**
Aim	To further investigate the use of tasks involving height.
Method	Subject sitting on standard chair. Table with radial gridlines placed in front of subject. Task 1 - Low stepped blocks. A block with 6 steps of height 5cm and depth 10cm was placed on 60° line. Objects were placed on the -60° line. Subject to move objects on to steps. Repeated with blocks on -60° line, objects on 60° line. Task 2 - High stepped blocks. Same as Task 1 except using block with 6 steps of height 10cm and depth 5cm. Task 3 - Hooks and rings. A pole of 80cm length, with 6 hooks at 10cm intervals and series of rings to go on hooks used instead of stepped blocks. Same as previous tasks.
Results + discussion	Stepped blocks - further steps require trunk elongation (on side reaching to) and good postural control. Higher steps provided increased challenge. Hooks and rings - also necessitated controlled trunk elongation.
Conclusions	Stacking tasks (previous investigations), stepped blocks, and hooks and rings are all suitable tasks in order to meet the aims of the practice regime.

Appendix D : The regime of practice

TASK	OBJECTIVE OF TASK	MOVEMENT	NUMBER OF REACHES
1. Cubes out.	**Equipment:** 8 "cubes" - 4 rounded and 4 square - colour coded to match colour of radial gridlines. Each cube will have a hole in the centre of the top of it. **Set up:** Cubes placed along midline of table. **Instructions:** To move each cube as far out as possible along the appropriately coloured gridline. Moving one round to one side and one square to the other, and repeating this sequence.	Midline > right > midline > left etc. Different angle each time.	8
2. Poles in.	**Equipment:** 8 poles - 4 rounded and 4 squared - colour coded to match gridlines and cubes. Each pole will stand upright when placed in holes in cubes. Each pole will have a series of holes through it, at different heights. **Set up:** As at end of task 1 + poles placed along midline of table, ordered so there are alternating shapes, but randomised colour order. **Instructions:** To place each pole in corresponding cube.	Midline > right > midline > left etc. Different angle each time.	8 (16)
3. Pegs in.	**Equipment:** 16 "pegs" - 8 rounded and 8 squared - colour coded so 2 match each pole/cube/gridline. **Set up:** As at end of task 2 + pegs placed along midline of table, ordered so that there are alternating shapes, but randomised colour order. **Instructions:** To place each peg through a hole in each corresponding pole, using hole as high up as possible. There will be 2 pegs through each pole.	Midline > right > midline > left etc. Different angle each time.	16 (32)
4. Hoops on.	**Equipment:** 16 "hoops" - colour coded to match other equipment. **Set up:** As at end of task 3 + hoops placed on midline. **Instructions:** To place hoops on corresponding pegs.	Midline > right > midline > left etc. Different angle each time.	16 (48)
5. Hoops off.	**Equipment:** as above. **Set up:** as at end of task 4. **Instructions:** To remove hoops from pegs and place them on midline. To take one from left then one from right etc.	Right > high midline> left > midline. Different angle each time.	16 (64)
6. Hoopla.	**Equipment:** As above + 5 hoops. **Set up:** as at end of task 5 + 5 hoops placed on pegs in 90° pole. **Instructions:** Move hoops from 90° on right to -90° on left; and then from -90° on left to 67.5° on right etc..	Right to left, through midline (at 90°), and left to right through midline (at 67.5 °).	35 (109)
7. Pegs out.	**Equipment:** as above. **Set up:** as at end of task 6. **Instructions:** To remove pegs from poles and place them on midline. To take one from left then one from right etc.	Right > midline > left > midline etc. Different angle each time.	16 (125)
8. Poles out.	**Equipment:** poles and cubes. **Set up:** as at end of task 6. **Instructions:** To remove poles from cubes and place them on midline. To take one from left then one from right etc.	Right > midline > left midline etc. Different angles each time.	8 (133)

9. Coins on Steps.	**Equipment:** 2 sets of "stepped blocks", with small container on each step. 15 'pound coins' and 15 '50 pence coins'. **Set up:** set of hollow steps placed on 90° and -90°. Objects placed along midline. **Instructions:** place pound coins through hole in highest step possible to the left; repeat with 50p coins to the right. Continue until all coins used.	Midline > left > midline > right (greater than 90°)	30 (163)
10. Stacking Tasks	**Equipment:** 10 stacking objects (cones). 5 of one colour, 5 of another. **Set up:** Stacking objects placed along midline. **Instructions:**		
	i) Move cone (colour A) as far out along 90° as possible, then cone (colour B) along -90°, then stack 4 of cones of appropriate colour on top of these.	Midline > right > midline > left (at 90°)	10 (173)
	ii) Move cone (colour A) as far out along 67.5° as possible, then cone (colour B) along -67.5°, then stack 4 cones of appropriate colour on top of these.	Midline > right > midline > left (at 67.5°)	10 (183)
	iii) Move cone (colour A) as far out along 45° as possible, then cone (colour B) along -45°, then stack 4 cones of appropriate colour on top of these.	Midline > right > midline > left (at 45°)	10 (193)
	iv) Move cone (colour A) as far out along 22.5° as possible, then cone (colour B) along -22.5°, then stack cones of appropriate colour on top of these.	Midline > right > midline > left (at 22.5°)	10 (203)

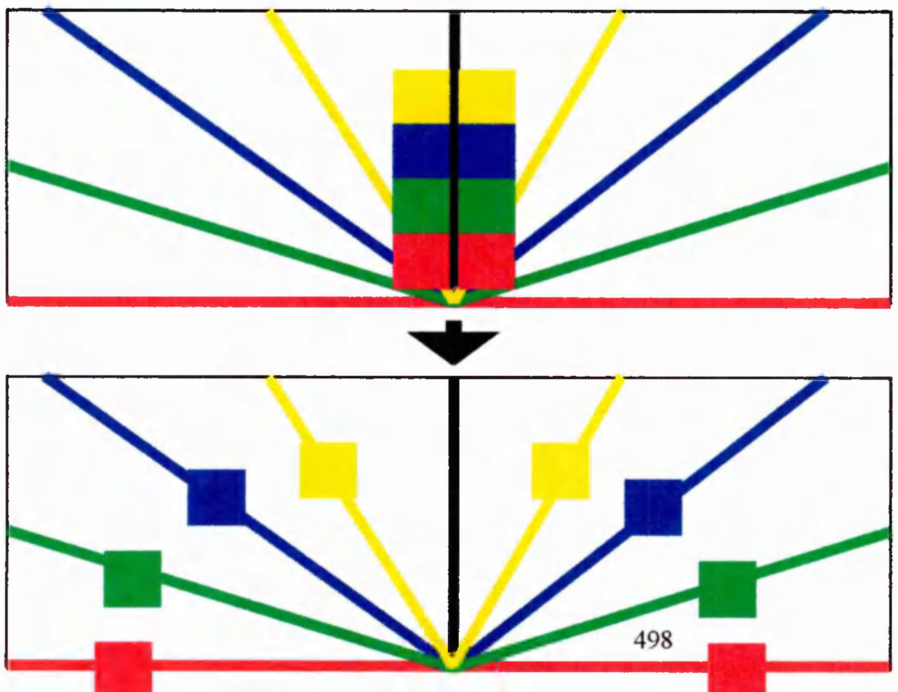
Appendix E : Instruction boards for practice regime

Task 1.

Move the cubes along the lines.

Move them as far out as you can.

Make sure the colours of the lines and cubes match.

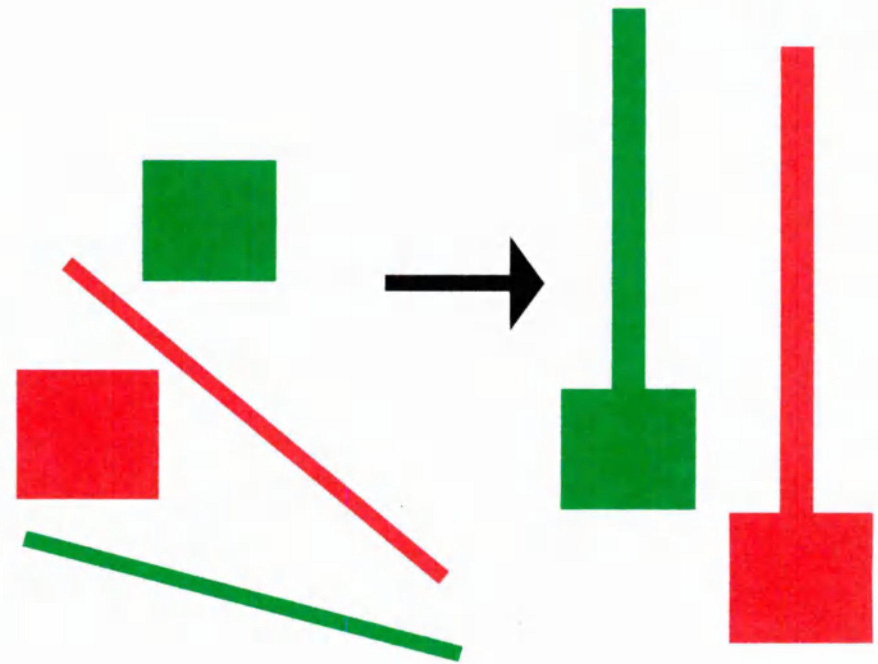


Task 2.

Put a pole into each cube.

Match the colours.

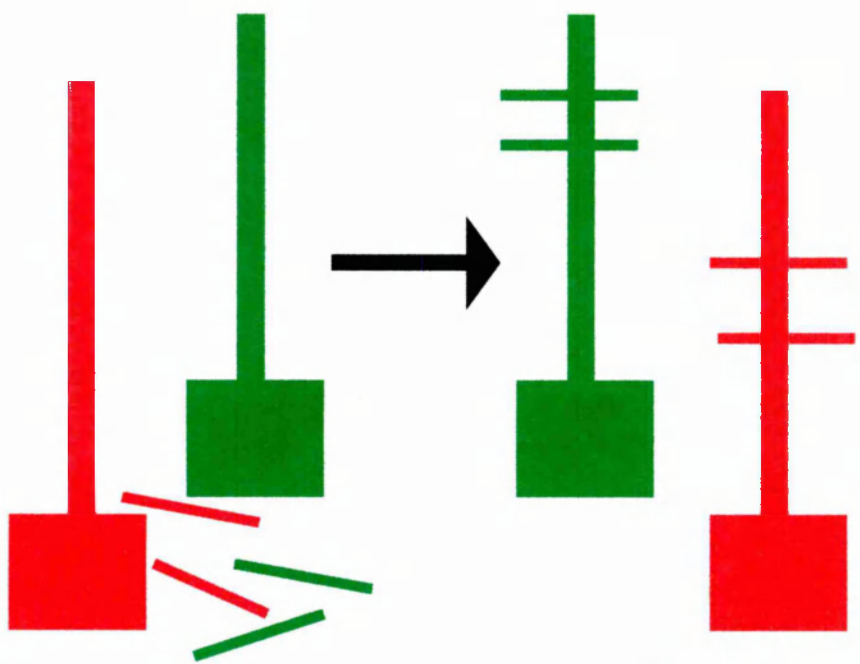
Match the shape of the hole and the pole.



Put 2 pegs into each pole.

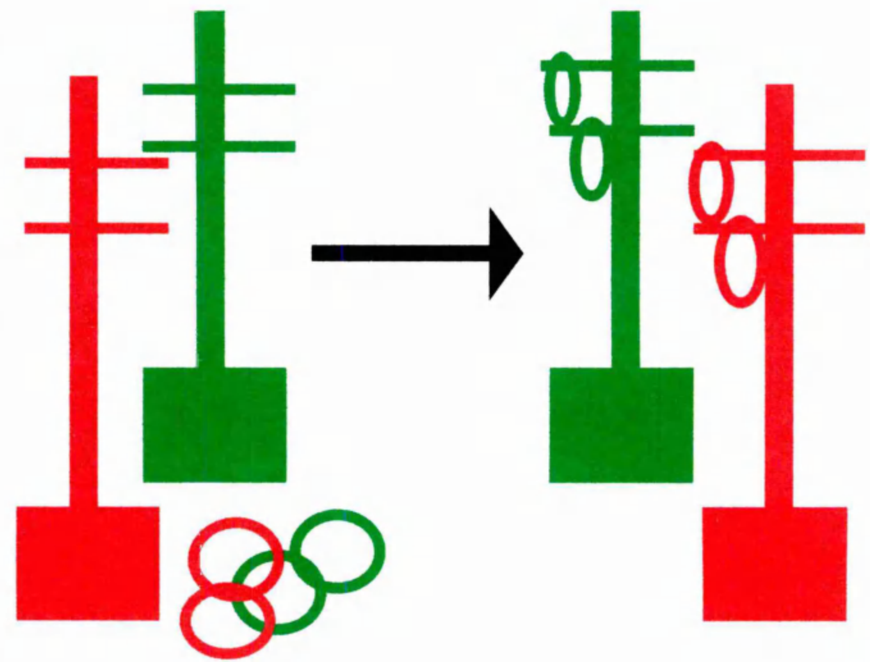
Put them as high up as you can.

Match the colours and shapes.



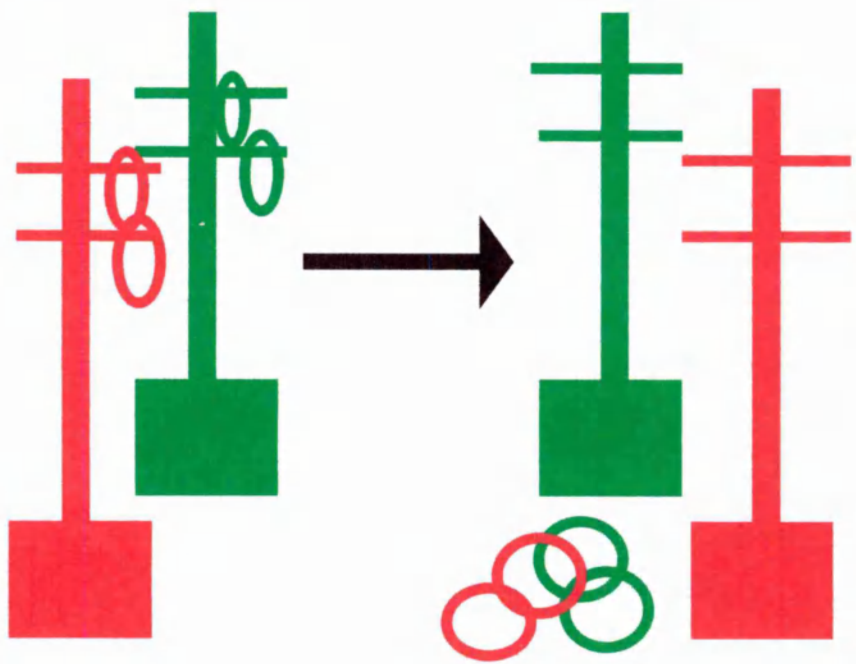
Put a hoop over each peg.

Match the colours.



Take the hoops off.

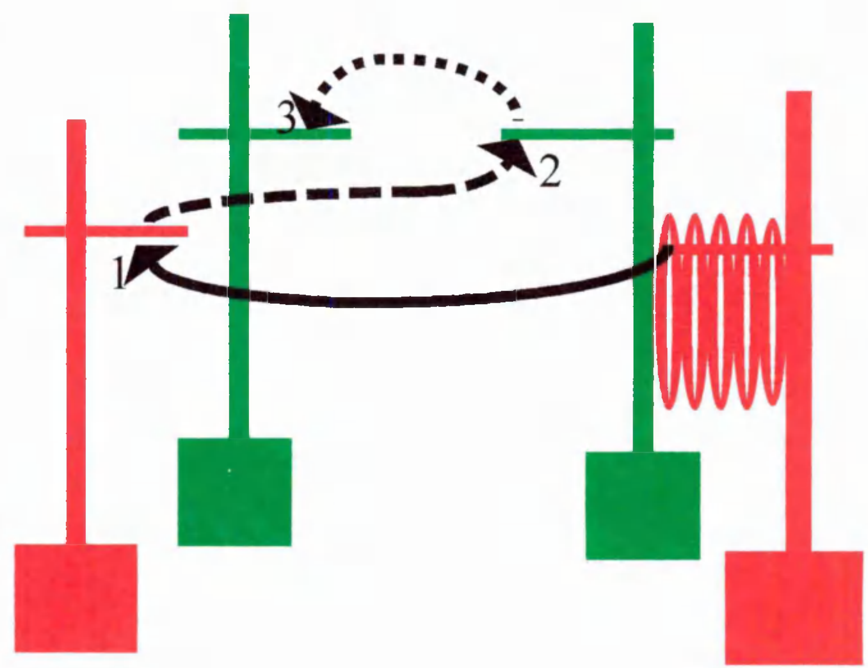
Take one from one side, then one from the other side.



Hoopla left and right.

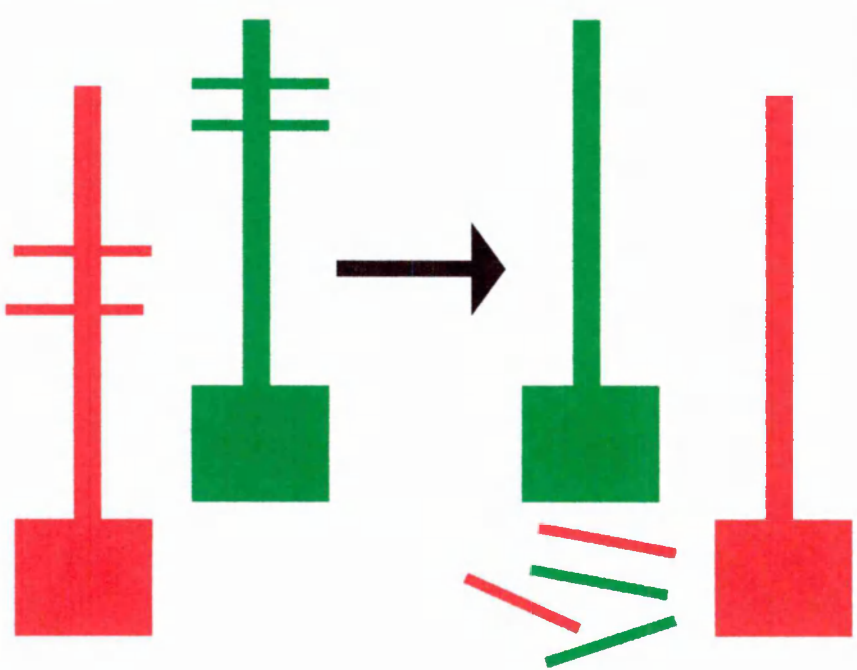
Move all the hoops from one side to the other, one at a time.

Move them back again, but on to the next coloured pole.



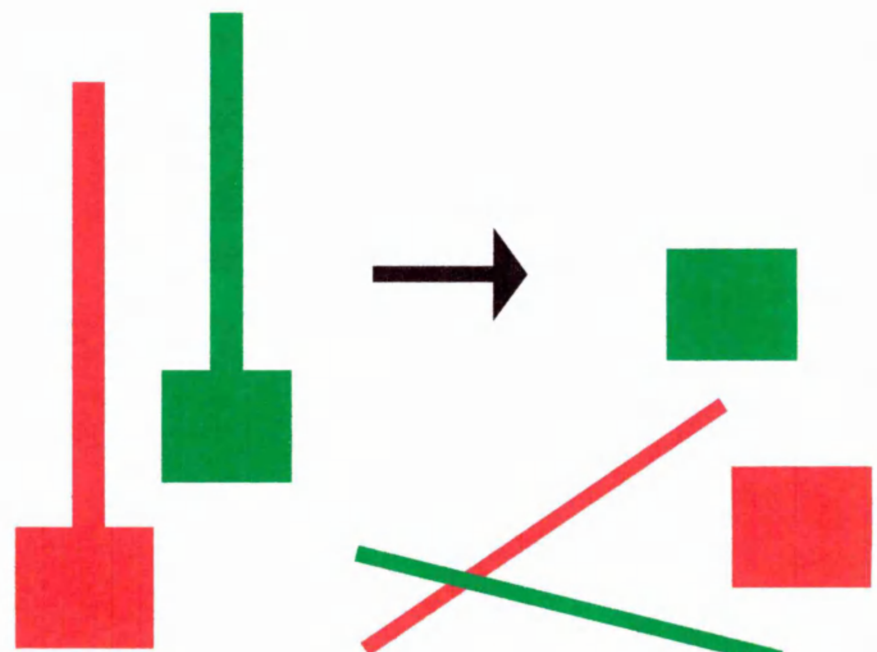
<u>Take the pegs out.</u>

Take one from one side,
then one from the other side.



<u>Take the poles out.</u>

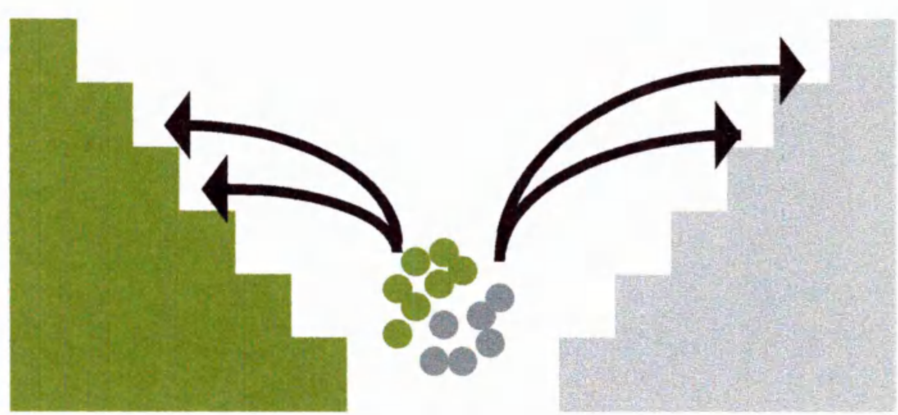
Take one from one side,
then one from the other side.



<u>Put the coins on the steps.</u>

Put them as high as you can.

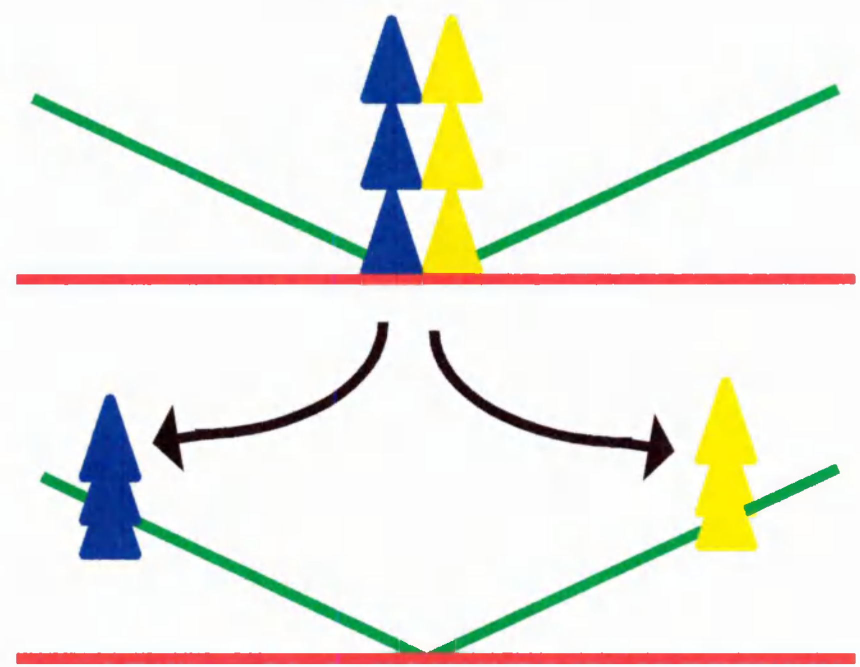
Put the £1 coins on the gold steps, and the 50p coins on the silver steps.



<u>Put cones as far out along the lines as you can.</u>

Move one colour of cone to one side, and another colour to the other side.

Stack the other cones on top, one at a time.



Appendix F : Scoring method for practice regime

Tasks 1-5, 7, 8:
Sum of distances out in task 1 * sum of height scores achieved in task 3.

Task 6:
Number of successful repetitions * 10.

Task 9:
Step number * number of coins * 5.

Task 10:
Distance of each cone * number stacked on top.

Total score = sum of above scores.

Each subject was verbally informed of the score at the end of each practice session, and was reminded of the number of repetitions at the beginning of the following practice session.

Appendix G : Healthy subjects - information sheets and consent form.

SUBJECT INFORMATION SHEET (Young subjects)

Measurement of Normal Sitting, Standing, Rising to Stand, Sitting Down and Reaching.

Purpose of this Study

There is a measurement system which has been developed in the Physiotherapy Department at QMC, which is designed to measure various aspects of human movement. It can measure timing and force parameters of sitting, standing, rising to stand, sitting down and reaching out. This system is going to be used as the objective measurement tool in a study of different physiotherapy treatments for people with strokes. However the first stage is to determine a range of normal measurements. Other similar studies have primarily used young volunteers; therefore subjects aged between 18 and 30 are desired in order to produce comparable data.

What will the Measurements Involve?

The measurement system involves a chair which stands on a small platform. There are a number of different "force plates" and "switches" within the chair and platform. The force plates are able to measure how much of your weight you are putting through different parts of your body; the switches can measure the speed at which you stand up and sit down. The measurements are non-invasive, and do not require any attachments to your body or clothing.

If you volunteer you would be asked to:-

- sit on the chair for about 30 seconds
- stand on the platform for about 30 seconds
- to stand up from the chair and then sit down again
- reach out to both sides from a sitting position.

You would be asked to repeat this three times in a row.

The measurements will all be done in the Human Performance Laboratory in the Physiotherapy Department. It will take about 10 minutes for the measurements to be taken.

Further Information

If you have want to volunteer or have any questions please contact me:-

Alex Brown..........Ext.3663 ......Room G79 (Leith Campus).

Alex Brown, Physiotherapy Research Student,
Queen Margaret College, Edinburgh.

SUBJECT INFORMATION SHEET

(Elderly subjects)

Measurement of Normal Sitting, Standing, Rising to Stand and Sitting Down.

Purpose of this Study

A measurement system has been developed that records the way people sit and stand, and the way they stand up from a chair and sit down again. This system will be able to measure how people with strokes sit and stand, assess if they have a problem, and work out if they are getting better. However, in order to know if a stroke patient is having problems with sitting, standing, rising to stand or sitting down we must know what is **normal**. To do this we need to take measurements from a group of people who are **healthy,** but are about the same age as people who most commonly have strokes. It is planned to use the information as part of a research project investigating different physiotherapy treatments for people who have had strokes.

What will the Measurements Involve?

The measurement system involves a chair which stands on a small platform. There are a number of different "force plates" and "switches" within the chair and platform. The force plates are able to measure how much of your weight you are putting through different parts of your body; the switches can measure the speed at which you stand up and sit down. However you cannot see these force plates and switches - they are all hidden in the chair and platform. When you sit on the chair or stand on the platform you cannot tell that they are there.

If you volunteer you would be asked to:-

- sit on the chair for about 30 seconds
- stand on the platform for about 30 seconds
- to stand up from the chair and then sit down again.
- to reach out to both sides from a sitting position, as far as you can.

You would be asked to repeat this three times in a row.

The measurements will all be done in the physiotherapy department, at the time of one of your fitness classes. It will take 10-15 minutes for the measurements to be taken.

No special clothing is required: just wear what you normally wear to the fitness class.

Please Note

Attending the fitness class does not mean that you have to volunteer for this study.
Even if you do volunteer you can withdraw again, without having to give a reason.

Further Information

If you have any questions please contact me:- Alex Brown..........Tel : 0131-317-3663
Or speak to the physiotherapist taking the class.

I will be at the next few classes, and will ask any volunteers to come to have their measurements taken then. Thank you for your time !!

Alex Brown, Physiotherapy Research Student,
Queen Margaret College, Edinburgh.

(Young and elderly subjects)

LOTHIAN RESEARCH ETHICS COMMITTEE

STANDARD CONSENT FORM

TITLE OF THE PROPOSED RESEARCH:

Sitting, Standing, Rising to Stand and Sitting Down in Healthy Subjects: Establishing a Normal Data Base using Force and Time Parameters.

NAME OF INVESTIGATOR:	ADDRESS:	TELEPHONE:
Alex Brown Physiotherapy Research Student	Physiotherapy Department Queen Margaret College Leith Campus Duke Street Edinburgh	0131-317-3663

FURTHER INFORMATION IS AVAILABLE FROM:

The physiotherapist taking the fitness class.

- **I agree to participate in this study.**
- **I have read this consent form and Subject Information Sheet and had the opportunity to ask questions about them.**
- **I understand that I am under no obligation to take part in this study and that a decision not to participate will not alter the treatment that I would normally receive.**
- **I understand that I have the right to withdraw from this study at any stage and that to do so will not affect my treatment.**
- **I understand that this is non-therapeutic research from which I cannot expect to derive any benefit.**

Signature of Subject..

Name of Subject:

Signature of Investigator: .... **Date:** ....

Appendix H : Hemiplegic subjects – information sheet and consent form

A STUDY OF PHYSIOTHERAPY EXERCISES FOR PEOPLE WITH STROKES

You have been asked to volunteer to take part in a study of physiotherapy. This information sheet tells you about the study, so that you can decide if you want to volunteer or not.

Purpose of this Study

After someone has had a stroke they generally need to have physiotherapy to help them get better. In the UK physiotherapy treatment normally happens in the physiotherapy gym, with one physiotherapist treating one patient. However, in Australia physiotherapists give patients exercises that they can do on their own. We want to see if there is any difference if patients who have had strokes do some exercises on their own. All the patients who take part in this study will still get their normal physiotherapy.

For this study we want one group of people with strokes to do all their normal therapy *plus* an exercise program and another group of people with strokes to do all their normal therapy but *no* extra exercises. The exercises are designed to help sitting balance and posture; they are all simple exercises that are done sitting down. We would take measurements of the sitting balance of both groups, and see if there are any differences between the groups.

What will happen if I agree to take part?

You would be assigned to either the "Exercising" group or the "Not Exercising" group. This assignment would be random - it would be decided by a computer and no one would be able to change which group you were put into.

If I was in the "exercise" group what would I have to do?

- You would do all your normal physiotherapy, occupational therapy etc. as usual.
- You would follow a daily exercise program every week day (Monday-Friday) for 4 weeks (If you went home before 4 weeks was completed it would not matter - you would not need to come in for any more exercises).

You would be taken to a physiotherapy room to do the exercises, at about 2pm (after lunch). The exercises would last for about one hour. You would be sitting down for all the exercises. A physiotherapist would be in the room with you.

- You would also need to have some measurements of your balance taken once a week, for 6 weeks (or less if you go home before then).

If I was in the "No exercise" group what would I have to do?

- You would do all your normal physiotherapy, occupational therapy etc. as usual.
- You would need to have some measurements of your balance taken once a week, for 6 weeks (or less if you go home before then).

How are the measurements of balance taken?
The measurement of balance would take about 15 minutes, one a week for 6 weeks. It would be taken in the physiotherapy gym.

A special chair that can measure balance has been designed. It is a normal chair which is on a platform. Hidden in the chair and platform there are devices like weighing scales that can measure your balance. When you sit on the chair or stand on the platform you cannot tell that the measuring devices are there. You would wear your normal clothes.

You would be asked to sit in the chair, stand up from the chair, stand on your own and then sit back down into the chair. You would be asked to reach out to the left and the right sides from a sitting position. If you needed help with any of these actions, someone would assist you.

Would any other information be needed?
Some information about your stroke, your physiotherapy treatment, and how you are getting on, would be taken from your doctor's, nurse's and physiotherapist's notes.

All this information would be confidential. Only the researchers will know what your results are.

Would I benefit from taking part in this study?
No. This is a preliminary study so it is unlikely that anyone will notice any direct benefits from taking part. We do not know if the exercises the people in the "exercise" group do will help them or not.

Do I have to take part in this study?
No. You do not have to take part. Your treatment in the hospital will be exactly the same whether you take part or not. Even if you do volunteer to take part you can change your mind and withdraw at any time, without having to give a reason. Withdrawing from the study would not affect any treatment that you got in the hospital.

When do I have to decide whether I want to take part or not?
I will come and see you again on ....at...

Further Information
If you, or any of your relatives, have any questions I can come and see you again - one of the nurses will contact me for you.
OR you can speak to Mark Smith (Physiotherapist) or Dr Dennis about this study.

Thank you for taking the time to read this and to think about volunteering!

Alex Brown, Physiotherapy Researcher,
Queen Margaret College, Edinburgh.

STANDARD CONSENT FORM

TITLE OF THE PROPOSED RESEARCH:

An Investigation into Independent Practice as an Addition to Physiotherapy Intervention for Patients with Recently Acquired Stroke.

NAME OF INVESTIGATOR:	**ADDRESS:**	**TELEPHONE:**
Alex Brown, Physiotherapy Researcher.	Physiotherapy Department Queen Margaret College Leith Campus Duke Street Edinburgh EH6 8HF.	0131-317-3663

Mr Mark Smith, Senior Physiotherapist, or Dr Dennis, Consultant Neurologist.

FURTHER INFORMATION IS AVAILABLE FROM:

- **I agree to participate/to the patient participating* in this study.**
- **I have read this consent form and Patient Information Sheet and had the opportunity to ask questions about them.**
- **I agree to the provision of any clinically significant information to my/the patient's consultant.**
- **I understand that I am/the patient is* under no obligation to take part in this study and that a decision not to participate will not alter the treatment that I/the patient * would normally receive.**
- **I understand that I have/the patient has* the right to withdraw from this study at any stage and that to do so will not affect my/their* treatment.**
- **I understand that this is non-therapeutic research from which I/the patient * cannot expect to derive any benefit.***

Signature of Patient/Relative/Member of Nursing Staff*..

Name of Patient:

Signature of Investigator: .... Date: ....

*** Delete as appropria**

Appendix I : HEALTHY SUBJECT DETAILS

Young subjects	gender	age (yr)	dominance	height (m)	LL length (m)	mass (Kg)	reaching arm
1	f	24	r	1.71	0.47	50.3	l
2	f	28	r	1.60	0.43	62.5	r
3	f	22	r	1.65	0.45	51.8	r
4	f	25	r	1.57	0.44	62.5	r
5	f	24	r	1.66	0.46	59.0	l
6	f	18	r	1.70	0.45	56.4	r
7	f	18	r	1.68	0.48	63.8	r
8	f	18	r	1.57	0.45	59.7	r
9	m	23	l	1.93	0.58	89.8	l
10	m	24	r	1.75	0.51	73.1	r
11	m	23	r	1.73	0.49	73.2	l
12	m	27	r	1.71	0.48	64.1	r
13	f	23	r	1.73	0.5	68.1	l
14	m	23	r	1.76	0.5	85.4	r
15	m	22	r	1.82	0.54	74.8	l
16	m	18	r	1.80	0.49	67.7	l
17	m	28	l	1.83	0.51	61.8	l
18	m	22	r	1.66	0.47	65.9	l
19	m	21	r	1.84	0.48	78.5	r
20	m	23	r	1.80	0.53	76.6	l

Elderly subjects	gender	age (yr)	dominance	height (m)	LL length (m)	mass (Kg)	reaching arm
1	f	71	r	1.60	0.45	71.9	r
2	f	66	r	1.60	0.43	57.7	r
3	m	67	l	1.62	0.46	85.7	r
4	f	73	r	1.69	0.47	63.7	l
5	f	76	r	1.62	0.46	60.6	r
6	f	67	r	1.63	0.51	75.3	l
7	f	79	r	1.59	0.46	59.7	r
8	f	60	r	1.66	0.45	64.9	l
9	f	70	r	1.70	0.49	74.9	l
10	f	70	r	1.66	0.47	78.1	l
11	f	73	r	1.65	0.46	59.2	r
12	f	68	r	1.60	0.47	65.4	l
13	m	71	r	1.75	0.48	71.8	l
14	m	74	r	1.68	0.46	55.5	r
15	f	64	r	1.57	0.42	54.8	l
16	f	68	r	1.57	0.43	54.9	l
17	f	68	r	1.63	0.49	75.0	r
18	m	66	r	1.81	0.52	81.3	r
19	m	72	r	1.78	0.53	68.4	r
20	m	71	r	1.74	0.48	73.4	l

Appendix J : HEMIPLEGIC SUBJECT DETAILS

subject	Group (c = control, p = practice)	Gender	Age (years)	Height (m)	Lower leg length (m)	Mass (kg)	side of hemiplegia	stroke classification	days from stroke to 1st test	Last test week completed	D/C details
1	p	F	52	1.55	0.43	69.3	L	TACI	38	6	
2	c	F	76	1.59	0.44	50.5	L	POCI	26	6	
3	c	M	66	1.70	0.45	53.7	L	PACI	12	3	self d/c
4	c	M	54	1.64	0.45	61.7	R	LACI	13	6	
5	p	F	82	1.55	0.44	70.6	R	TACI	14	0	refused
6	c	F	54	1.65	0.42	46.8	R	TACI	15	5	home
7	c	M	37	1.68	0.43	52.7	R	TACI	11	5	home
8	p	F	86	1.57	0.45	54.0	L	PACI	13	6	
9	c	M	86	1.94	0.56	82.8	R	POCI	11	5	home
10	c	M	66	1.73	0.48	70.0	L	LACI	4	6	
11	p	F	69	1.52	0.41	58.6	L	PACI	28	6	
12	c	M	69	1.71	0.47	63.1	L	PACI	48	6	
13	p	F	71	1.57	0.46	56.4	L	LACI	5	6	
14	p	F	75	1.60	0.45	56.6	L	PACI	13	2	# NOF
15	c	F	61	1.60	0.45	61.1	R	LACI	8	5	home
16	c	F	78	1.65	0.44	53.0	L	TACI	55	0	rip
17	p	F	68	1.65	0.46	43.4	R	LACI	15	6	
18	c	M	76	1.83	0.50	60.1	R	PICH	18	2	home
19	p	F	72	1.52	0.43	39.5	L	LACI	9	3	home
20	c	M	82	1.88	0.51	43.5	L	TACI	12	1	Chest infection
21	c	F	86	1.52	0.43	58.9	R	PACI	39	6	
22	c	F	51	1.63	0.45	48.9	R	PICH	8	4	home
23	c	M	57	1.68	0.46	54.2	L	LACI	7	6	
24	c	M	72	1.73	0.47	60.8	L	TACI	13	6	
25	p	F	83	1.50	0.42	51.9	L	LACI	8	2	home
26	c	F	84	1.47	0.36	38.2	L	PICH	19	6	
27	c	M	70	1.63	0.44	49.6	L	LACI	12	6	
28	c	M	75	1.65	0.46	71.0	R	TACI	13	6	

Appendix K : MEAN OUTCOME VARIABLES FOR HEALTHY AND HEMIPLEGIC SUBJECTS

The following tables list the mean outcome variables for sitting, standing, rising to stand, std, reaching to the same side and reaching across to the opposite side for the young and elderly healthy subjects and for the hemiplegic subjects.

KEY

Sit = mean SI during sitting
Std = mean SI during standing
RTSon = mean SI during seat-on phase of rising to stand
RTSoff = mean SI during seat-off phase of rising to stand
RTStime = time (s) to rise to stand
SDoff = mean SI during seat-off phase of sitting down
SDon = mean SI during seat-on phase of sitting down.
SDtime = time (s) to sit down
RSpeak = peak SI during reaching to the same side
RSafter = mean SI during sitting after reaching to the same side
RStime = time (s) to reach to the same side
RApeak = peak SI during reaching across to the opposite side
RAafter = mean SI during sitting after reaching across to the opposite side
RAtime = time (s) to reach across to the opposite side

For hemiplegic subjects:-
c = control group subject
p = practice group subject
- = subject discharged

0 – 6 refer to test week 0 – test week 6.

Subject (young)	sit	std	RTSon	RTSoff	RTStime	SDoff	SDon	SDtime	RSpeak	RSafter	RStime	RApeak	RAafter	RAtime
1	-0.014	-0.125	-0.079	-0.024	2.61	-0.080	-0.037	3.45	0.844	0.008	5.42	-0.835	-0.029	6.19
2	-0.004	-0.039	-0.024	0.020	2.65	-0.010	-0.045	3.54	0.910	0.038	6.90	-0.928	-0.077	8.27
3	-0.028	-0.016	-0.032	0.041	2.30	0.030	0.006	2.71	0.946	0.082	7.48	-0.861	0.068	9.22
4	-0.019	0.038	-0.042	0.081	1.95	0.088	-0.054	1.99	0.614	-0.025	5.05	-0.713	-0.095	5.93
5	-0.007	-0.039	-0.027	0.001	3.09	-0.027	0.020	3.61	0.876	-0.012	5.98	-0.802	-0.021	9.09
6	-0.094	0.077	-0.039	-0.026	1.88	0.046	0.003	2.60	0.961	0.023	6.92	-0.857	-0.046	8.23
7	-0.009	-0.183	-0.049	-0.080	1.47	-0.231	-0.100	2.16	0.861	0.097	7.11	-0.901	0.086	8.07
8	0.030	-0.014	0.013	-0.112	1.90	-0.008	0.045	2.20	0.795	-0.042	6.85	-0.767	-0.044	6.85
9	0.032	0.033	0.012	0.053	2.73	0.028	0.033	3.93	0.767	0.054	6.51	-0.681	-0.031	8.36
10	-0.018	0.030	-0.009	0.081	1.82	0.044	-0.017	2.67	0.804	-0.029	7.29	missing	missing	missing
11	-0.016	0.017	0.026	0.021	2.15	0.019	-0.016	3.07	0.929	0.012	6.77	-0.862	0.011	7.18
12	-0.042	-0.001	-0.030	0.085	3.13	0.005	0.008	3.40	0.838	0.017	6.17	-0.844	-0.052	7.06
13	-0.011	0.085	-0.024	0.053	1.39	0.091	-0.044	2.61	0.937	0.020	8.99	-0.900	-0.003	8.24
14	-0.019	-0.002	-0.026	-0.039	2.38	0.004	-0.002	2.42	0.892	0.043	6.84	-0.809	0.004	5.89
15	0.047	0.013	0.063	-0.044	2.33	0.049	0.030	2.72	0.864	0.039	6.97	-0.817	0.000	6.15
16	-0.018	-0.001	-0.035	0.076	2.43	0.008	0.002	2.49	0.892	-0.083	6.93	-0.892	0.015	5.87
17	0.053	-0.050	0.062	0.059	2.48	-0.028	0.147	2.32	0.820	0.053	6.67	-0.939	-0.049	5.72
18	0.012	-0.129	0.002	-0.113	2.69	-0.144	-0.018	3.23	0.787	0.024	8.84	-0.773	-0.031	8.25
19	0.016	0.017	-0.003	-0.028	2.66	0.028	-0.063	3.46	0.839	0.071	6.41	-0.780	-0.013	8.11
20	0.057	-0.060	0.032	-0.161	1.70	-0.016	0.034	2.58	0.786	0.051	5.68	-0.834	-0.027	6.81

Young healthy subject data for all functions.

Subject (elderly)	sit	std	RTSon	RTSoff	RTStime	SDoff	SDon	SDtime	RSpeak	RSafter	RStime	RApeak	RAafter	RAtime
1	-0.065	0.132	-0.072	0.026	2.48	0.201	-0.056	3.01	0.819	0.113	7.60	-0.766	0.110	6.81
2	0.078	0.099	0.068	-0.020	2.15	0.134	0.100	2.40	0.667	-0.009	5.94	-0.788	-0.130	5.21
3	0.012	0.046	-0.004	0.016	2.14	0.054	0.111	3.05	0.705	-0.027	8.58	-0.832	-0.008	6.57
4	0.038	0.058	0.031	-0.144	2.30	0.052	0.082	2.57	0.883	-0.066	6.80	-0.891	-0.014	7.47
5	-0.043	0.106	-0.043	0.085	2.57	0.109	-0.078	3.14	0.893	0.061	9.00	-0.778	0.054	7.50
6	-0.045	-0.070	-0.084	-0.014	3.00	-0.115	-0.106	3.57	0.788	0.056	8.70	-0.813	-0.134	6.09
7	-0.103	-0.006	-0.010	-0.110	2.51	-0.035	0.009	3.12	0.810	0.190	8.94	-0.674	0.117	7.39
8	-0.040	-0.050	-0.041	0.125	2.93	-0.025	0.033	3.45	0.918	0.093	7.21	-0.865	-0.043	7.98
9	-0.134	-0.047	-0.125	0.042	2.53	-0.022	-0.133	3.69	0.847	-0.134	7.80	-0.888	-0.288	9.53
10	-0.054	-0.041	-0.045	0.089	1.96	-0.047	-0.037	3.26	0.837	0.219	9.44	-0.795	-0.094	7.36
11	-0.024	0.123	0.029	-0.015	2.31	0.028	0.017	3.53	0.925	0.137	7.58	-0.721	0.020	8.07
12	0.004	0.102	-0.004	-0.036	3.06	0.044	-0.004	2.76	0.935	0.035	8.75	-0.787	0.003	6.51
13	0.031	-0.017	-0.026	0.094	1.85	-0.010	0.015	2.21	0.935	0.035	8.75	-0.835	-0.049	8.27
14	-0.036	0.119	-0.023	0.119	2.29	0.076	-0.092	2.54	0.739	0.015	5.65	-0.924	-0.078	7.30
15	0.019	0.068	-0.081	-0.119	2.07	0.083	-0.102	2.61	0.873	0.021	11.45	-0.891	-0.010	7.75
16	0.042	-0.012	-0.062	0.025	2.15	-0.019	-0.030	3.49	0.808	0.140	11.88	-0.800	0.172	11.60
17	0.057	0.259	0.043	0.318	2.25	0.263	0.073	3.01	0.846	0.031	4.85	-0.735	-0.099	5.75
18	-0.011	-0.054	-0.032	-0.016	2.27	-0.032	-0.016	2.27	0.897	0.093	8.05	-0.762	0.022	7.35
19	0.039	0.026	0.027	0.094	2.93	0.027	0.094	2.93	0.699	-0.085	6.67	-0.643	-0.085	6.39
20	0.054	-0.015	0.060	0.056	2.91	0.060	0.056	2.91	0.689	0.117	9.41	-0.623	0.068	10.02

Elderly healthy subject data for all functions.

Subject	group	Sit 0	Sit 1	Sit 2	Sit 3	Sit 4	Sit 5	Sit 6	Std 0	Std 1	Std 2	Std 3	Std 4	Std 5	Std 6	RTSon 0	RTSon 1	RTSon 2	RTSon 3	RTSon 4	RTSon 5	RTSon 6
1	p	0.058	0.029	0.110	0.096	0.174	0.076	0.024		0.395	0.482	0.331	0.250	0.274	0.286			0.035	0.071	0.045	0.150	0.101
2	c	-0.079	-0.036	-0.102	0.066	0.182	-0.004	0.008				-0.063	-0.595	-0.321	-0.403				-0.192	-0.326	-0.092	-0.030
3	c	-0.203	-0.131	-0.109	-0.178	-	-	-		0.187	0.000	0.414	-	-	-		0.204	0.148	0.191	-	-	-
4	c	-0.018	0.019	0.018	-0.039	-0.006	0.026	0.076		0.261	0.283	0.117	0.185	0.263	0.199		0.028	0.107	-0.013	0.134	0.160	0.169
5	p	0.043	-	-	-	-	-	-		-	-	-	-	-	-		-	-	-	-	-	-
6	c	0.075	0.015	0.042	0.094	0.101	0.017	-		-0.147	0.128	0.203	0.099	0.185	-		0.250	0.075	0.165	0.175	0.203	-
7	c	-0.186	0.127	-0.173	-0.067	-0.026	0.076	-		-0.010	0.162	0.355	0.033	0.130	-		0.021	0.256	0.266	0.085	0.115	-
8	p	0.085	-0.092	0.071	0.209	0.127	0.245	0.156					-0.159	-0.092	0.031							0.066
9	c	-0.139	-0.098	-0.134	-0.073	0.065	-0.001	-			0.148	-0.068	0.013	-0.090	-							
10	c	0.143	0.152	0.129	0.063	0.063	0.037	0.059		-0.187	0.090	0.107	0.195	0.195	0.056					0.040	0.156	0.075
11	p	0.103	0.126	0.121	-0.047	0.255	0.139	0.141			-0.201		-0.138	-0.205	-0.291			-0.127	-0.164	-0.143	-0.134	-0.121
12	c	0.128	-0.042	0.114	0.157	-0.039	0.209	0.224														
13	p	0.069	0.143	0.121	0.130	0.066	0.077	0.143					0.190	-	0.099							
14	p	0.312	0.102	0.058	-	-	-	-		-0.089	0.069	-	-	-	-		-0.056	-0.008	-	-	-	-
15	c	-0.024	-0.062	-0.092	0.032	0.033	0.011	-		-0.166	0.081	0.124	-0.096	0.063	-		-0.064	0.083	0.235	0.139	0.142	-
16	c	-0.019	-	-	-	-	-	-		-	-	-	-	-	-		-	-	-	-	-	-
17	p	-0.051	0.167	-0.054	-0.183	-0.117	-0.084	-0.028				0.249	0.272	0.128	0.240			0.118	-0.054	0.008	0.001	0.055
18	c	-0.029	0.039	-0.057	-	-	-	-	0.040	0.006	0.051	-0.038	-0.038	-0.038	-0.038	-0.106	0.018	0.063	-	-	-	-
19	p	0.107	-0.106	-0.017	-0.125	-	-	-	0.282	0.317	0.317	0.266	-	-	-	0.001	0.154	0.126	0.121	-	-	-
20	c	-0.154	-0.019	-	-	-	-	-			-	-	-	-	-			-0.013	0.055	0.097	0.037	-0.092
21	c	0.007	-0.159	-0.032	0.108	0.180	0.167	0.006			-0.038	-0.097	-0.140	-0.131	-0.115							
22	c	-0.062	0.054	-0.040	-0.002	-0.010	-	-		0.060	0.091	0.151	0.126	-	-			0.179	0.072	0.061	-	-
23	c	-0.070	-0.133	-0.020	-0.052	-0.107	0.063	-0.049		0.182	0.330	0.074	0.308	0.212	0.403		0.392	0.618	0.314	0.269	0.100	0.317
24	c	-0.041	0.044	0.049	-0.010	-0.024	0.025	0.020														
25	p	0.084	0.031	-0.100	-	-	-	-	-0.078	0.065	0.090	-	-	-	-		0.038	0.056	-	-	-	-
26	c	0.020	0.032	0.271	0.062	0.093	0.055	0.145														
27	p	0.189	0.269	0.103	0.285	0.108	0.115	0.214				-0.011	0.135	0.052	0.088				-0.164	0.301	0.003	0.027
28	p	-0.042	-0.010	-0.004	0.060	-0.007	0.065	0.064	0.133	0.014	0.136	0.067	0.006	0.051	0.040		-0.002	0.068	0.142	0.083	0.166	0.178

Hemiplegic subject data for sitting, standing and seat-on phase of rising to stand.

subject	group	RTSoff 0	RTSoff 1	RTSoff 2	RTSoff 3	RTSoff 4	RTSoff 5	RTSoff 6	RTStime 0	RTStime 1	RTStime 2	RTStime 3	RTStime 4	RTStime 5	RTStime 6	SDoff 0	SDoff 1	SDoff 2	SDoff 3	SDoff 4	SDoff 5	SDoff 6
1	p			0.727	0.433	0.448	0.800	0.665			3.29	3.18	2.34	1.42	3.30		0.496	0.358	0.289	0.457	0.386	0.517
2	c				-0.220	-0.372	-0.447	-0.534				8.44	4.74	3.70	3.64				-0.061	-0.376	-0.273	-0.373
3	c		-0.032	0.143	0.361	-	-	-		3.87	5.06	1.32	-	-	-		-0.032	0.011	0.294	-	-	-
4	c		-0.268	0.215	0.248	0.447	0.125	0.009		3.16	6.38	2.20	2.54	2.94	4.62			0.382	0.244	0.518	0.653	0.369
5	p		-	-	-	-	-	-		-	-	-	-	-	-		-	-	-	-	-	-
6	c		-0.249	0.459	-0.007	0.116	0.383	-		4.78	3.02	1.84	2.62	1.90	-		0.423		0.207	0.227	0.166	-
7	c		-0.100	0.357	0.199	0.192	0.375	-		2.16	1.60	1.04	2.76	2.40	-		0.256	0.127	0.472	0.197	0.181	-
8	p							0.153							15.42							
9	c							-							-							-
10	c					0.219	0.178	0.124					6.14	5.18	4.93			0.093		0.251	0.191	0.143
11	p			-0.183	-0.149	-0.002	-0.110	-0.241			5.02	9.68	6.76	5.98	14.74			-0.149		-0.165	-0.087	-0.187
12	c																					
13	p																					
14	p		0.134	0.021	-	-	-	-		6.84	2.02	-	-	-	-		0.046	0.170	-	-	-	-
15	c		0.005	0.126	0.130	0.131	0.262	-		5.38	3.75	3.74	2.94	1.72	-		-0.039	0.099	0.265	0.039	0.194	-
16	c		-	-	-	-	-	-		-	-	-	-	-	-		-	-	-	-	-	-
17	p			0.212	0.267	0.185	0.262	0.171			10.46	10.10	8.64	3.92	8.80				0.471	0.176	0.177	-0.111
18	c	-0.062	-0.207	-0.032	-	-	-	-	10.64	3.44	3.24	-	-	-	-		0.017	0.187	-	-	-	-
19	p	0.290	0.276	0.149	0.279	-	-	-	9.14	3.08	2.28	2.60	-	-	-		0.446	0.264	0.354	-	-	-
20	c			0.012	0.079	0.214	0.173	0.109			9.44	5.88	3.24	4.66	4.70			0.049	-0.034	-0.038	0.062	-0.025
21	c																					
22	c			-0.073	0.252	0.061	-	-			10.62	1.66	1.86	-	-			0.155	0.228	0.260	-	-
23	c		0.816	0.319	0.481	0.192	0.194	0.640		3.46	2.46	6.82	4.72	5.46	4.62		0.469	0.627	0.654	0.719	0.607	0.661
24	c																					
25	p		0.126	0.136	-	-	-	-		5.86	5.14	-	-	-	-		0.106	0.261	-	-	-	-
26	c																					
27	c				-0.151	-0.151	-0.044	-0.074				7.64	11.54	4.80	4.52						0.192	0.043
28	c		0.176	-0.098	0.158	0.064	0.058	0.091		6.00	6.86	3.78	4.84	3.68	4.44		0.060	0.336	0.354	0.169	0.174	0.218

Hemiplegic subject data for seat-off phase of rising to stand, time to rise to stand and seat-off phase of sitting down.

Subject	Group	SDon 0	SDon 1	SDon 2	SDon 3	SDon 4	SDon 5	SDon 6	SDtime 0	SDtime 1	SDtime 2	SDtime 3	SDtime 4	SDtime 5	SDtime 6
1	p		-0.062	-0.029	-0.028	-0.068	-0.077	0.046		4.34	3.92	2.6	4.28	4.14	2.82
2	c				-0.034	-0.071	0.105	-0.151				3.94	2.5	2.96	2.97
3	c		0.155	-0.134	0.109	-	-	-		2.86	2.94	3.28	-	-	-
4	c			0.063	-0.045	0.265	0.184	0.223			4.36	4.14	4.38	3.98	5.42
5	p		-	-	-	-	-	-		-	-	-	-	-	-
6	c		0.169		0.303	0.258	0.229	-		2.94		3.02	2.88	2.02	-
7	c		-0.328	-0.235	-0.292	0.140	0.511	-		2.16	2.32	3	6.1	2	-
8	p														
9	c							-							-
10	c			0.022		-0.019	0.130	0.097			2		3.02	3.72	4.92
11	p			-0.194		-0.241	-0.201	-0.006			3	-	6.96	4.32	4.12
12	c														
13	p														
14	p		0.031	0.164	-	-	-	-		5.28	3.72	-	-	-	-
15	c		-0.210	-0.102	0.129	0.053	0.093	-		3.54	1.78	3.5	4	3.4	-
16	c		-	-	-	-	-	-		-	-	-	-	-	-
17	p				0.356	-0.251	-0.084	-0.146				3.86	3.4	3.14	1.64
18	c		-0.002	0.123	-	-	-	-		4.12	4.38	-	-	-	-
19	p		0.290	0.107	0.112	-	-	-		4.32	4.26	5.66	-	-	-
20	c			0.094	0.324	0.201	0.167	0.100			2.86	2.32	2.04	2.7	3.9
21	c														
22	c			-0.326	-0.012	0.176	-	-			2.78	2.02	2.44	-	-
23	c		0.044	-0.162	0.267	0.561	0.084	0.036		4.44	2.08	4.54	4.8	4.26	4.26
24	c														
25	p		-0.043	0.071	-	-	-	-		3.02	3.64	-	-	-	-
26	c														
27	c						0.042	-0.263						2.84	4.2
28	c		-0.097	0.062	0.176	-0.088	0.039	0.068		2.82	3.5	3.98	6.02	6.38	6.04

Hemiplegic subject data for seat-on phase of sitting down and time to sit down.

Subject	Group	RSpeak 0	RSpeak 1	RSpeak 2	RSpeak 3	RSpeak 4	RSpeak 5	RSpeak 6	RSafter 0	RSafter 1	RSafter 2	RSafter 3	RSafter 4	RSafter 5	RSafter 6	RStime 0	RStime 1	RStime 2	RStime 3	RStime 4	RStime 5	RStime 5
1	p	0.681	0.740	0.727	0.792	0.763	0.695	0.754	-0.080	-0.102	-0.104	-0.142	-0.178	-0.130	-0.041	8.09	7.77	7.83	8.78	7.39	7.89	8.43
2	c	0.620	0.659	0.544	0.607	0.554	0.711	0.704	0.113	0.063	0.119	0.028	0.032	0.250	0.017	14.30	12.27	11.62	11.79	10.52	9.08	10.93
3	c	0.867	0.804	0.895	0.875	-	-	-	0.272	-0.043	0.215	-0.068	-	-	-	7.58	7.34	8.99	5.69	-	-	-
4	c	0.760	0.778	0.835	0.820	0.851	0.824	0.841	0.090	0.128	0.037	-0.146	-0.027	-0.021	0.026	8.44	9.64	9.05	10.25	9.71	9.52	8.89
5	p	0.664	-	-	-	-	-	-	-0.024	-	-	-	-	-	-	10.80	-	-	-	-	-	-
6	c	0.608	0.625	0.822		0.894	0.843	-	0.277	-0.063	0.109		0.133	0.234	-	15.29	8.79	8.80	7.27	9.29	7.35	-
7	c	0.703	0.745	0.693	0.680	0.775	0.770	-	-0.018	0.068	-0.014	-0.187	0.031	0.145	-	8.03	9.00	6.14	6.35	7.03	5.99	-
8	p	0.678	0.681	0.665	0.634	0.624	0.499	0.632	-0.068	0.219	-0.049	-0.067	-0.133	-0.263	-0.169	7.39	13.64	13.45	12.19	14.65	13.53	14.17
9	c	0.694	0.559	0.488	0.892	0.785	0.684	-	0.166	-0.101	-0.183	0.073	0.071	0.082	-	14.49	11.77	11.33	11.21	9.47	7.90	-
10	c	0.568	0.617	0.649	0.665	0.632	0.657	0.661	-0.144	-0.101	-0.002	-0.016	-0.044	0.013	-0.013	6.34	4.79	5.74	6.51	7.55	4.69	6.33
11	p	0.587	0.648	0.667	0.646	0.706	0.712	0.667	0.050	-0.034	-0.064	0.235	-0.138	-0.027	0.133	13.11	14.63	12.06	11.90	13.29	13.50	14.05
12	c	0.758	0.740	0.718	0.658	0.770	0.665	0.625	-0.056	0.121	-0.038	-0.034	0.170	-0.085	-0.008	12.03	10.47	11.72	14.06	11.55	10.90	13.37
13	p	0.697	0.607	0.576	0.668	0.636	0.637	0.681	-0.131	-0.207	-0.196	-0.204	-0.020	-0.178	-0.120	11.79	12.35	10.87	8.45	10.61	8.41	10.49
14	p	0.482	0.824	0.872	-	-	-	-	-0.317	0.125	0.232	-	-	-	-	10.75	10.51	9.88	-	-	-	-
15	c	0.755	0.665	0.735	0.746	0.775	0.847	-	-0.020	-0.106	-0.049	-0.011	0.154	0.144	-	11.14	9.31	11.25	9.32	10.10	9.99	-
16	c	0.428	-	-	-	-	-	-	0.049	-	-	-	-	-	-	12.37	-	-	-	-	-	-
17	p	0.285	0.679	0.546	0.500	0.489	0.536	0.642	-0.089	0.243	-0.160	-0.205	-0.321	-0.149	-0.127	9.06	9.07	9.73	9.89	9.39	8.77	9.36
18	c	0.595	0.639	0.707	-	-	-	-	0.061	-0.070	0.131	-	-		-	7.80	9.15	9.31	-	-	-	-
19	p	0.567	0.799	0.779	0.764	-	-	-	-0.087	0.326	-0.025	0.158	-	-	-	12.83	6.57	7.28	7.91	-	-	-
20	c	0.285	0.641	-	-	-	-	-	-0.150	0.221	-	-	-	-	-	10.40	15.41	-	-	-	-	-
21	c	0.020	0.490	0.508	0.771	0.766	0.815	0.809	-0.314	-0.201	-0.064	0.303	0.483	0.299	0.098	13.89	11.24	12.21	12.68	11.55	14.57	15.99
22	c	0.646	0.743	0.772	0.852	0.885	-	-	-0.188	-0.018	-0.038	-0.159	-0.065	-	-	14.73	12.30	12.51	14.31	13.01	-	-
23	c	0.834	0.850	0.830	0.795	0.814	0.856	0.861	-0.093	0.049	-0.029	0.032	0.037	0.073	0.183	11.60	12.05	9.95	12.94	11.15	8.70	13.50
24	c	0.518	0.583	0.474	0.612	0.659	0.543	0.609	0.082	0.080	-0.010	-0.079	-0.004	-0.004	0.009	10.11	9.21	12.27	12.65	8.61	10.21	7.22
25	p	0.802	0.743	0.800	-	-	-	-	0.172	-0.046	0.150	-	-	-	-	10.13	9.12	10.41	-	-	-	-
26	c	0.284	0.606	0.433		0.905	0.956	0.909	-0.024	0.075	0.204		0.127	-0.014	0.062	10.06	12.33	14.99		13.93	13.43	15.45
27	c	0.419	0.530	0.367	0.545	0.437	0.281	0.194	-0.202	-0.256	-0.179	-0.253	-0.282	-0.165	-0.338	8.91	4.98	10.97	7.16	5.89	7.24	5.97
28	c	0.782	0.787	0.792	0.707	0.743	0.746	0.694	-0.108	-0.066	-0.049	0.141	-0.113	-0.033	0.095	9.07	7.25	9.37	9.07	10.77	8.10	8.05

Hemiplegic subject data for peak SI during and mean SI after reaching to the same side and time taken to reach to the same side.

Subject	Group	RApeak 0	RApeak 1	RApeak 2	RApeak 3	RApeak 4	RApeak 5	RApeak 6	RAafter 0	RAafter 1	RAafter 2	RAafter 3	RAafter 4	RAafter 5	RAafter 6	RAtime 0	RAtime 1	RAtime 2	RAtime 3	RAtime 4	RAtime 5	RAtime 6
1	p	-0.782	-0.901	-0.786	-0.826	-0.715	-0.667	-0.769	-0.069	-0.117	-0.142	-0.136	-0.162	-0.145	-0.082	9.63	7.19	8.38	9.81	7.66	10.28	10.11
2	c	-0.743	-0.619	-0.498	-0.716	-0.670	-0.609	-0.709	0.018	-0.148	0.085	-0.056	0.030	0.068	-0.113	13.73	11.50	10.83	10.79	8.39	8.63	9.92
3	c	-0.774	-0.961	-0.935	-0.895	-	-	-	0.138	0.071	0.267	0.005	-	-	-	7.79	7.15	11.43	9.44	-	-	-
4	c	-0.971	-0.898	-0.910	-0.841	-0.870	-0.883	-0.847	0.131	0.112	0.011	-0.001	0.022	0.010	-0.030	13.75	11.76	9.00	11.55	8.13	9.25	10.46
5	p	-0.621	-	-	-	-	-	-	0.047	-	-	-	-	-	-	13.85	-	-	-	-	-	-
6	c	-0.650	-0.683	-0.783	-0.921	-0.936	-0.946	-	-0.126	-0.097	0.114	0.158	0.090	0.156	-	14.67	6.95	6.89	9.88	10.92	5.65	-
7	c	-0.740	-0.766	-0.799	-0.858	-0.702	-0.731	-	-0.035	0.015	-0.028	-0.168	0.107	0.221	-	10.32	9.89	8.17	9.29	7.38	7.57	-
8	p	-0.601	-0.533	-0.713	-0.756	-0.671	-0.787	-0.675	-0.187	-0.067	-0.008	-0.163	-0.321	-0.481	-0.357	12.43	15.07	14.94	12.73	14.29	14.50	14.90
9	c	-0.773	-0.867	-0.908	-0.711	-0.693	-0.885	-	-0.184	-0.068	-0.208	-0.189	0.201	0.173	-	13.43	13.13	8.20	11.79	11.05	10.35	-
10	c	-0.429	-0.594	-0.562	-0.674	-0.593	-0.582	-0.595	-0.178	-0.154	-0.020	-0.083	-0.085	-0.022	-0.088	6.54	6.07	7.48	5.88	5.29	6.45	8.13
11	p	-0.532	-0.574	-0.773	-0.599	-0.717	-0.752	-0.669	-0.118	-0.114	-0.135	-0.178	-0.267	-0.081	-0.090	14.70	15.15	14.69	14.08	13.10	13.65	14.51
12	c	-0.774	-0.667	-0.787	-0.803	-0.732	-0.786	-0.829	-0.179	-0.025	-0.136	-0.247	-0.005	-0.229	-0.613	13.55	11.48	12.99	14.38	15.25	14.45	15.10
13	p	-0.663	-0.729	-0.752	-0.820	-0.821	-0.899	-0.826	-0.073	-0.196	-0.319	-0.182	-0.011	-0.200	-0.100	12.79	11.95	10.28	13.88	12.07	11.19	10.71
14	p	-0.810	-0.707	-0.681	-	-	-	-	-0.413	0.018	0.199	-	-	-	-	11.99	11.81	8.48	-	-	-	-
15	c	-0.763	-0.820	-0.849	-0.821	-0.695	-0.715	-	-0.146	-0.167	-0.171	-0.093	0.051	0.011	-	10.65	9.98	11.35	11.17	9.67	11.56	-
16	c	-0.416	-	-	-	-	-	-	0.013	-	-	-	-	-	-	14.75	-	-	-	-	-	-
17	p	-0.600	-0.629	-0.721	-0.798	-0.720	-0.895	-0.872	-0.065	0.209	-0.121	-0.190	-0.311	-0.188	-0.100	10.58	9.64	8.94	10.32	10.15	9.53	8.95
18	c	-0.644	-0.772	-0.719	-	-	-	-	0.003	-0.029	0.113	-	-	-	-	8.53	10.31	10.60	-	-	-	-
19	p	-0.691	-0.641	-0.822	-0.787	-	-	-	-0.173	0.164	-0.063	0.159	-	-	-	11.37	10.59	9.27	8.00	-	-	-
20	c	-0.685	-0.515	-	-	-	-	-	0.333	0.007	-	-	-0.084	-	-	5.09	15.25	-	-	-	-	-
21	c	-0.169	-0.660	-0.709	-0.475	-0.542	-0.606	-0.714	0.273	-0.134	-0.061	0.120	0.329	0.251	0.127	8.09	13.89	13.29	11.49	12.81	14.25	15.11
22	c	-0.971	-0.896	-0.892	-0.707	-0.807	-	-	-0.246	0.046	-0.043	0.023	-0.044	-	-	16.11	14.71	13.34	13.09	14.31	-	-
23	c	-0.637	-0.487	-0.799	-0.408	-0.609	-0.481	-0.764	0.168	0.188	0.102	0.179	0.037	0.302	-0.053	8.92	13.11	15.44	13.27	9.11	14.16	14.76
24	c	-0.207	-0.316	-0.376	-0.612	-0.559	-0.627	-0.578	0.034	0.033	-0.191	-0.156	-0.086	-0.046	-0.072	10.63	10.38	11.33	12.87	9.19	13.47	11.23
25	p	-0.611	-0.546	-0.524	-	-	-	-	0.170	-0.065	0.137	-	-	-	-	10.15	9.07	8.45	-	-	-	-
26	c	-0.717	-0.835	-0.601		-0.840	-0.763	-0.786	-0.192	-0.277	-0.574	-	-0.296	-0.175	-0.360	12.33	12.99	13.32		14.80	15.17	14.92
27	c	-0.807	-0.746	-0.213	-0.723	-0.704	-0.706	-0.697	-0.263	-0.275	-0.066	-0.284	-0.280	-0.323	-0.376	10.65	5.21	11.16	7.91	11.96	10.99	8.93
28	c	-0.833	-0.839	-0.800	-0.481	-0.809	-0.859	-0.661	-0.033	-0.007	0.067	0.234	-0.087	-0.008	0.136	8.58	11.47	9.21	11.67	14.45	9.83	11.83

Hemiplegic subject data for peak SI during and mean SI after reaching across to the opposite side and time taken to reach across to the opposite side.

Appendix L: Distance and height of reach during practice regime

		Distance reached at each angle during Task 1. (measured to nearest 0.05m)								Height reached at each angle during Task 3 (at distances achieved in Task 1). (heights at 0.1m increments)							
	Day	90°	67.5°	45°	22.5°	-22.5°	-45°	-67.5°	-90°	90°	67.5°	45°	22.5°	-22.5°	-45°	-67.6°	-90°
Subject A.	1	0.95	0.80	0.80	0.75	0.70	0.65	0.65	0.70	0.60	0.60	0.50	0.50	0.50	0.50	0.50	0.50
	2	0.70	0.65	0.50	0.60	0.60	0.60	0.60	0.60	0.50	0.50	0.40	0.50	0.40	0.40	0.40	0.40
	3	0.55	0.60	0.60	0.55	0.60	0.60	0.60	0.60	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.40
	4	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.40
	5	0.70	0.70	0.70	0.70	0.65	0.65	0.70	0.65	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60
	6	0.70	0.70	0.75	0.75	0.70	0.70	0.65	0.65	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60
	7	0.55	0.60	0.60	0.60	0.50	0.60	0.60	0.55	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
	8	0.55	0.60	0.60	0.60	0.60	0.60	0.60	0.65	0.60	0.50	0.50	0.50	0.50	0.50	0.50	0.50
	9	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60
	10	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60
	12	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
	13	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.40
	14	0.70	0.70	0.60	0.60	0.70	0.70	0.60	0.60	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
	15	0.70	0.70	0.70	0.60	0.60	0.60	0.60	0.60	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
	16	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
	17	0.70	0.70	0.60	0.60	0.70	0.70	0.60	0.60	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
	18	0.60	0.60	0.70	0.70	0.60	0.60	0.70	0.70	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
	19	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
	20	0.70	0.70	0.70	0.70	0.70	0.60	0.60	0.60	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
B.	1	0.80	0.70	0.60	0.50	0.45	0.50	0.55	0.60	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40
Subject C.	1	0.60	0.50	0.40	0.40	0.55	0.50	0.50	0.30	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40
	2	0.40	0.40	0.50	0.50	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40
	4	0.40	0.45	0.45	0.45	0.45	0.45	0.45	0.50	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40
	6	0.60	0.60	0.55	0.50	0.50	0.50	0.45	0.50	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40
	9	0.70	0.70	0.55	0.55	0.45	0.45	0.50	0.55	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40
	12	0.75	0.70	0.65	0.60	0.60	0.60	0.65	0.60	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40
	13	0.70	0.70	0.60	0.50	0.50	0.55	0.60	0.60	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40
	14	0.65	0.60	0.60	0.55	0.50	0.50	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40
	15	0.60	0.55	0.55	0.45	0.45	0.40	0.45	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40
	16	0.85	0.65	0.60	0.55	0.55	0.55	0.55	0.60	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40
	17	0.75	0.65	0.65	0.65	0.60	0.55	0.60	0.65	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40
	18	0.80	0.75	0.70	0.65	0.60	0.60	0.65	0.60	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40
	19	0.70	0.65	0.60	0.65	0.60	0.55	0.60	0.55	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40
	20	0.75	0.70	0.70	0.70	0.65	0.60	0.60	0.60	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40
Subject D.	1	0.65	0.65	0.60	0.50	0.60	0.50	0.65	0.65	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20
	4	0.75	0.75	0.70	0.60	0.60	0.60	0.60	0.60	0.40	0.30	0.30	0.30	0.30	0.30	0.30	0.30
	5	0.70	0.60	0.60	0.55	0.55	0.55	0.55	0.65	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30
	6	0.75	0.60	0.55	0.55	0.55	0.60	0.60	0.70	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30
	7	0.70	0.65	0.60	0.60	0.60	0.65	0.70	0.75	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30
	8	0.75	0.70	0.65	0.60	0.60	0.60	0.65	0.65	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40
	9	0.80	0.65	0.70	0.60	0.65	0.70	0.70	0.85	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40
	10	0.80	0.65	0.70	0.60	0.65	0.70	0.70	0.90	0.50	0.50	0.40	0.40	0.40	0.50	0.50	0.40
	11	0.85	0.65	0.70	0.60	0.70	0.80	0.70	0.85	0.50	0.40	0.40	0.50	0.40	0.40	0.50	0.50
	12	0.85	0.75	0.70	0.70	0.70	0.75	0.70	0.90	0.50	0.40	0.40	0.50	0.40	0.50	0.50	0.50
	13	0.85	0.75	0.70	0.60	0.60	0.70	0.70	0.90	0.50	0.40	0.40	0.50	0.40	0.50	0.50	0.40
	16	0.70	0.60	0.65	0.60	0.60	0.70	0.75	0.80	0.50	0.50	0.50	0.40	0.40	0.40	0.50	0.50
	17	0.70	0.70	0.65	0.65	0.70	0.70	0.70	0.85	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40
	18	0.85	0.80	0.75	0.65	0.70	0.80	0.75	0.95	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40
	19	0.85	0.75	0.75	0.70	0.70	0.80	0.80	0.95	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
	20	0.80	0.75	0.70	0.65	0.70	0.75	0.80	0.95	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40

		Distance reached at each angle during Task 1. (measured to nearest 0.05m)								Height reached at each angle during Task 3 (at distances achieved in Task 1). (heights at 0.1m increments)							
	Day	90°	67.5°	45°	22.5°	-22.5°	-45°	-67.5°	-90°	90°	67.5°	45°	22.5°	-22.5°	-45°	-67.5°	-90°
Subject E.	2	0.95	0.80	0.65	0.65	0.70	0.75	0.75	0.80	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70
	3	0.95	0.80	0.80	0.70	0.70	0.75	0.70	0.90	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
	9	0.65	0.50	0.55	0.55	0.50	0.50	0.55	0.55	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
	10	0.60	0.55	0.50	0.55	0.55	0.55	0.60	0.60	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
	11	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40
	12	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40
	13	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40
	14	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40
	15	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40
	16	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40
	17	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40
	20	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40
Subject F.	1	0.75	0.65	0.65	0.65	0.65	0.65	0.70	0.80	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40
	2	0.90	0.75	0.65	0.60	0.60	0.65	0.75	0.90	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40
	3	0.55	0.55	0.55	0.50	0.55	0.50	0.55	0.50	0.70	0.60	0.40	0.40	0.40	0.40	0.60	0.70
	4	0.50	0.60	0.65	0.55	0.50	0.55	0.50	0.50	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40
	5	0.65	0.65	0.65	0.60	0.55	0.60	0.70	0.65	0.50	0.40	0.40	0.40	0.50	0.40	0.40	0.40
	6	0.85	0.85	0.70	0.65	0.55	0.70	0.80	0.75	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40
	7	0.75	0.75	0.70	0.60	0.70	0.70	0.75	0.80	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
	8	0.80	0.70	0.70	0.65	0.70	0.75	0.65	0.85	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
	9	0.65	0.70	0.65	0.55	0.65	0.65	0.65	0.65	0.50	0.50	0.50	0.50	0.40	0.40	0.40	0.50
	12	0.85	0.90	0.75	0.75	0.70	0.70	0.60	0.75	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
	13	0.85	0.75	0.75	0.55	0.65	0.70	0.80	0.90	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40
	14	0.65	0.75	0.65	0.55	0.70	0.75	0.75	0.80	0.40	0.50	0.40	0.40	0.50	0.50	0.40	0.40
Subject G.	1	0.55	0.45	0.45	0.50	0.50	0.60	0.50	0.65	0.50	0.50	0.40	0.50	0.40	0.40	0.50	0.40
	4	0.45	0.45	0.40	0.40	0.40	0.45	0.50	0.50	0.40	0.40	0.40	0.50	0.50	0.50	0.50	0.50
	6	0.50	0.55	0.50	0.45	0.50	0.50	0.60	0.60	0.40	0.40	0.50	0.50	0.50	0.50	0.50	0.50
	7	0.65	0.55	0.50	0.50	0.50	0.50	0.55	0.55	0.50	0.50	0.40	0.40	0.40	0.40	0.50	0.50
	8	0.60	0.55	0.50	0.50	0.50	0.50	0.50	0.50	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40
	9	0.50	0.50	0.50	0.50	0.50	0.50	0.60	0.50	0.50	0.40	0.40	0.50	0.40	0.40	0.40	0.50
	10	0.60	0.60	0.60	0.50	0.45	0.50	0.50	0.50	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40
	11	0.60	0.55	0.55	0.45	0.55	0.55	0.65	0.60	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40
	17	0.60	0.60	0.50	0.50	0.50	0.50	0.50	0.50	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40
	18	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40
	19	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40
	20	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40
Subject H.	1	0.85	0.70	0.65	0.60	0.55	0.60	0.65	0.70	0.60	0.60	0.50	0.50	0.50	0.60	0.60	0.50
	3	0.70	0.65	0.60	0.54	0.50	0.60	0.60	0.60	0.50	0.50	0.50	0.60	0.60	0.50	0.50	0.50
	4	0.80	0.70	0.60	0.55	0.50	0.60	0.70	0.75	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
	5	0.80	0.70	0.65	0.60	0.60	0.65	0.70	0.75	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60
	6	0.85	0.75	0.70	0.65	0.60	0.65	0.65	0.75	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60
	7	0.85	0.75	0.70	0.65	0.60	0.65	0.70	0.75	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60
	8	0.90	0.80	0.75	0.60	0.60	0.65	0.70	0.80	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.50
	10	0.90	0.85	0.75	0.60	0.60	0.70	0.80	0.75	0.60	0.50	0.60	0.60	0.60	0.60	0.60	0.60
	11	0.85	0.75	0.70	0.65	0.80	0.65	0.70	0.70	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60
	12	0.80	0.75	0.70	0.60	0.60	0.65	0.70	0.80	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.50
	13	0.85	0.75	0.70	0.60	0.60	0.65	0.65	0.70	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60
	14	0.90	0.80	0.70	0.60	0.60	0.65	0.70	0.80	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60

	Distance reached at each angle during Task 1. (measured to nearest 0.05m)								Height reached at each angle during Task 3 (at distances achieved in Task 1). (heights at 0.1m increments)							
Day	**90°**	**67.5°**	**45°**	**22.5°**	**-22.5°**	**-45°**	**-67.5°**	**-90°**	**90°**	**67.5°**	**45°**	**22.5°**	**-22.5°**	**-45°**	**-67.5°**	**-90°**
Subject I.																
1	0.80	0.75	0.70	0.65	0.60	0.65	0.70	0.70	0.60	0.50	0.50	0.50	0.40	0.40	0.40	0.40
2	0.85	0.75	0.70	0.65	0.70	0.75	0.75	0.75	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
3	0.85	0.80	0.70	0.65	0.65	0.65	0.70	0.70	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.60
4	0.80	0.75	0.70	0.65	0.70	0.70	0.75	0.80	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
6	0.90	0.80	0.75	0.70	0.65	0.70	0.70	0.70	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
7	0.85	0.75	0.70	0.65	0.60	0.60	0.70	0.75	0.60	0.50	0.50	0.50	0.50	0.50	0.50	0.50
8	0.75	0.75	0.70	0.65	0.60	0.65	0.70	0.70	0.70	0.60	0.60	0.50	0.60	0.50	0.50	0.60
9	0.80	0.75	0.70	0.65	0.65	0.65	0.70	0.75	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60
11	0.75	0.75	0.65	0.60	0.60	0.60	0.65	0.70	0.60	0.50	0.50	0.50	0.40	0.50	0.50	0.50